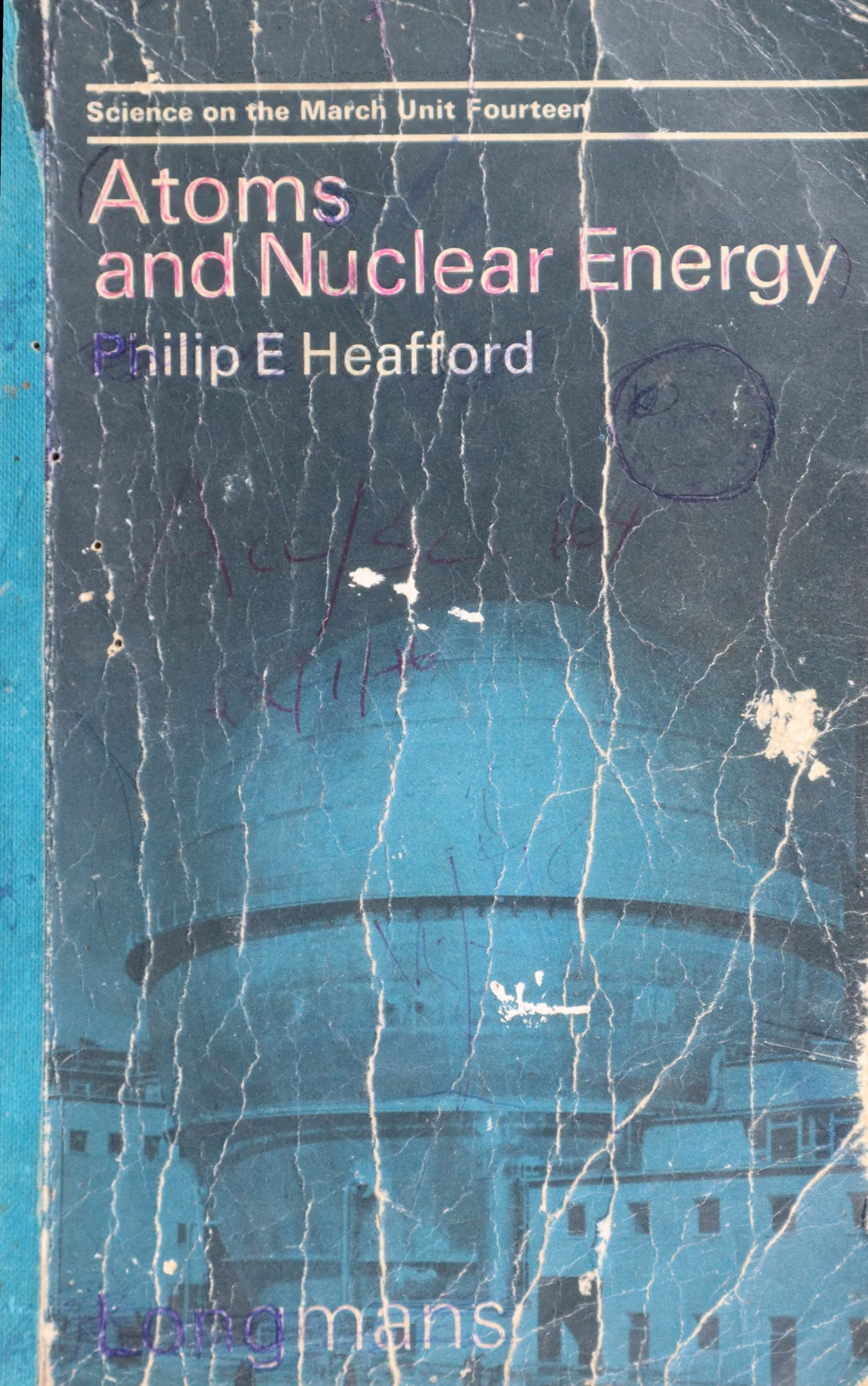
Science on the March Unit Fourteen

Atoms and Nuclear Energy

Philip E Heafford



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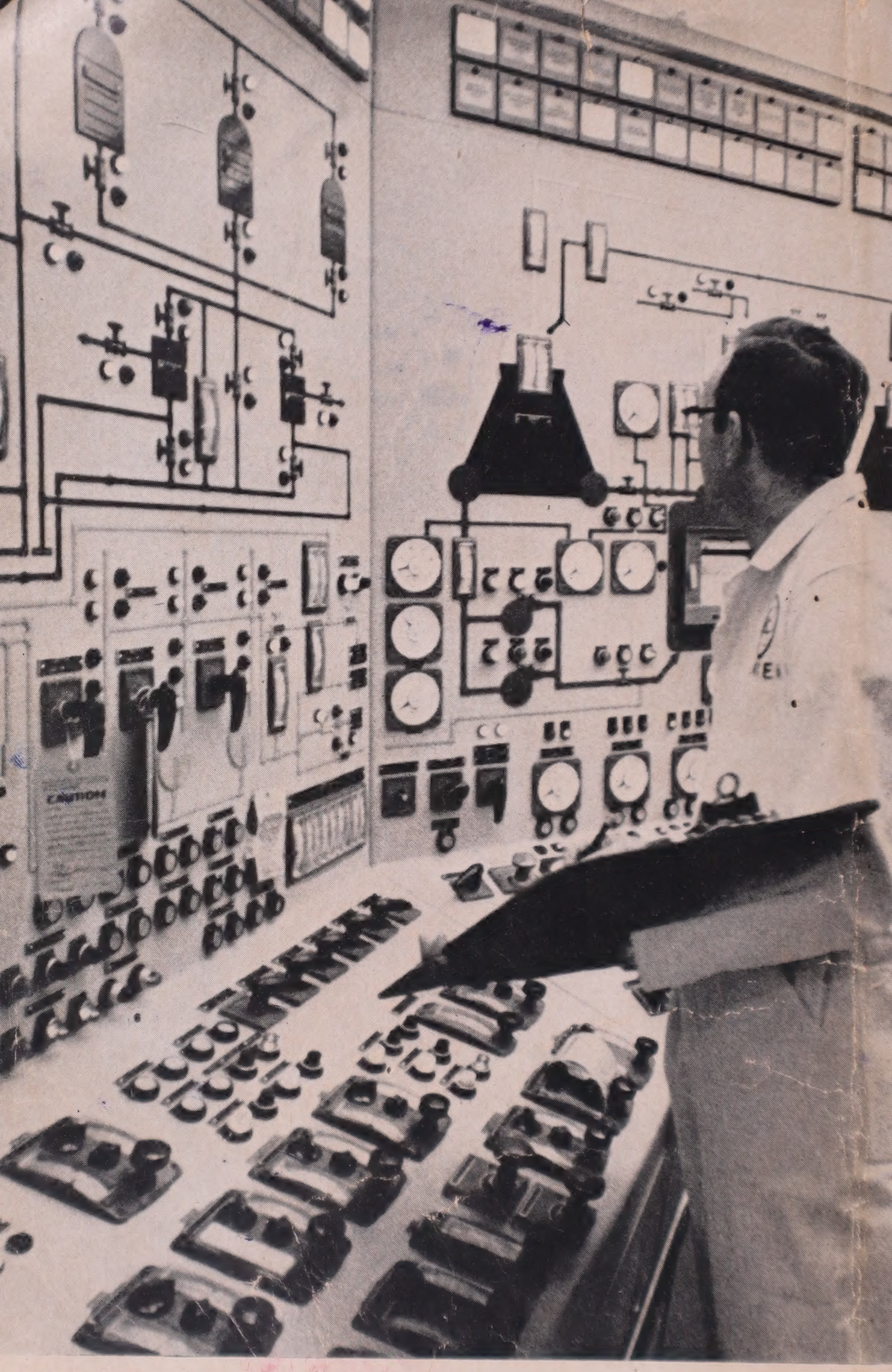

From this nerve centre, highly skilled technicians monitor and control the nuclear propulsion system of the American nuclear-powered ship *Savannah*

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Science on the March
Unit fourteen
General editor Charles H. Dobinson

Atoms and Nuclear Energy

Philip E. Heafford
Department of Education
University of Oxford

Longmans

Science on the March
Titles in this series

1 The Air and You
2 Water and Life
3 The Weather and the Earth
4 Life and Food
5 Health
6 Energy and Engines
7 Hearing and Seeing
8 Electric Currents
9 Magnets and Electric Power
10 Earth and Universe
11 Heating and Cooling
12 Birth and Growth
13 Metals and Man
14 Atoms and Nuclear Energy

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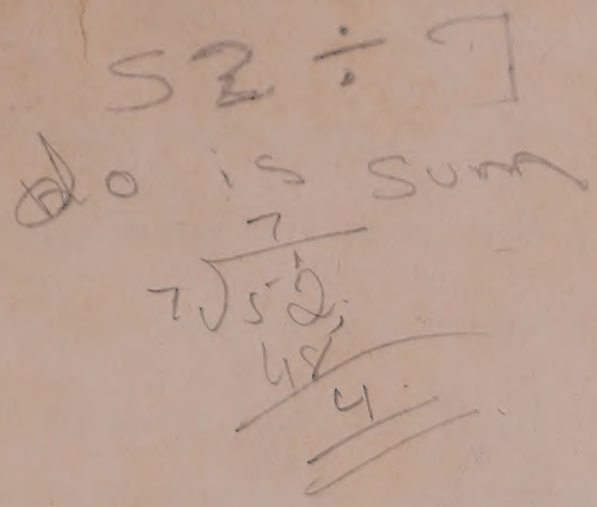

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Glossary of Scientific Terms

Alpha particle A positively charged particle consisting of two protons and two neutrons and hence identical with the nucleus of a helium atom. It has four units of mass.

Atom The smallest unit of an element which possesses the properties of the element. An atom is a system composed of a positively charged nucleus and a number of negatively charged electrons which travel in orbits around the nucleus.

Atomic number The number of protons that are in the nucleus of each atom of a particular element.

Atomic theory John Dalton's atomic theory of matter tried to explain chemical facts and laws. It assumes that matter is made up of atoms, all those of the same element being identical. Chemical combination is due to attraction between atoms in simple numerical proportions.

Atomic weight The ratio of the mass of an atom of a particular element to the mass of an atom of oxygen taken as 16. Because there may be several isotopes in any sample of an element involved in a chemical reaction the atomic weight is unlikely to be a whole number as is the mass number of an isotope.

Beta particle An electron given off during radioactivity from an unstable atomic nucleus.

Cathode rays A stream of electrons which travel away from the surface of the negatively charged electrode, or cathode, when an electrical discharge occurs in a tube containing a gas at very low pressure.

Chain reaction A rapidly spreading continuous process of fission caused by the fission of one nucleus setting off two- or three-fold fissions in adjacent nuclei.

Charge A quantity of electricity. The smallest charge is the charge of a single electron.

Compound A substance composed of the atoms of two or more elements combined together chemically in definite proportions.

Control rod A rod used in controlling a nuclear reactor. It is made of material (boron or cadmium) which easily absorbs neutrons.

Coolant A liquid or gas used to convey heat from a nuclear reactor to a heat exchanger.

Critical size The least size of a mass of fission material in which disintegration will continue as a chain reaction once it has been started.

Cyclotron An apparatus used for giving charged particles extremely high speeds so that they can break up the nuclei of atoms.

Deuterium An isotope of hydrogen also called heavy hydrogen. It has one proton and one neutron in its nucleus, and one electron in orbit. In ordinary hydrogen there is no neutron.

Electrolysis The chemical decomposition of a substance brought about by the passage of an electric current through it when it is in solution or in a molten state.

Electron A fundamental particle of an atom with almost negligible mass and having one unit of negative electric charge. The electrons in the atom determine the chemical properties of the element. In a neutral atom the number of electrons equals the number of protons.

Element A substance which cannot be decomposed by chemical means into simpler substances. There are over a hundred different kinds of element known at the present time.

Energy The capacity a body possesses which enables it to do work. Various forms of energy exist that can be transformed one into the other, and they include potential, kinetic, chemical, electrical, heat, and nuclear energy.

Fission The splitting of the nucleus of an atom into two or more parts usually with the release of a large quantity of energy.

Fundamental particles The main ones are the proton, neutron, and electron that in various combinations make the different atoms.

Fusion The joining together of the nuclei of light atoms to form a heavier and more tightly bound nucleus—usually with the release of a large amount of energy.

Gamma rays Electromagnetic radiation given out by radioactive atoms when they disintegrate. Like X-rays they travel farther through light materials than through dense materials.

Geiger counter An instrument that detects alpha particles, or beta particles, or gamma rays. It is usually connected to an amplifier which registers these radiations either as audible clicks or as numerals on a meter.

Generator, electric A machine that converts mechanical energy of rotation into alternating current electrical energy.

Half-life The time required for one half of the atoms of a radioactive substance to disintegrate.

Heat exchanger A boiler in which heat from the hot coolant passing through a nuclear fission reactor is transferred to cold water. The water changes into high-pressure steam which is then used to drive turbines attached to electric generators.

Heavy water The oxide of deuterium. It is a liquid similar to ordinary water in which it occurs in small amounts. It is used as a moderator in some fission reactors.

Helium A chemically inert gas which was first discovered in the sun. It is the second lightest element. The nucleus of a helium atom, a helium ion, is also called an alpha particle. Its atomic number is 2.

Hydrogen The lightest element, is a gas that burns with a pale blue flame. The nucleus of a hydrogen atom, or a hydrogen ion, is also called a proton. Its atomic number is 1.

Hydrogen bomb A nuclear fusion device in which light atoms move together at very high speeds and fuse into new heavier atoms emitting enormous amounts of energy.

Ion An atom or a molecule carrying an electric charge.

Isotope Atoms of the same element having the same atomic number but different numbers of neutrons in their nuclei are known as isotopes of that element. Nearly all elements found naturally are mixtures of several isotopes. Isotopes of the same element have exactly the same chemical properties.

Mass number The number of protons plus the number of neutrons in the nucleus of any particular isotope of an element is the mass number of that isotope. The number of protons in the nucleus determines which element it is and the number of neutrons determines which isotope it is.

Mixture A mixture may contain several different kinds of matter and these may be separated by mechanical or physical means. Most mixtures can be made in any proportions.

Moderator A substance used in a nuclear reactor to slow down the speeds of neutrons so that they have a greater possibility of creating a nuclear fission.

Molecule A molecule is a group of atoms held closely together, and is the smallest portion of a substance capable of independent existence whilst still retaining the properties of the original substance.

Neutron One of the fundamental particles of the nucleus of an atom. It has approximately the same mass as that of a proton and has no electric charge.

Nuclear bomb A device capable of exploding violently producing an uncontrolled nuclear fission in the form of a chain reaction. It contains before disintegration two pieces of fissionable material each one less than and together greater than the critical size.

Nuclear energy The energy derived from the nucleus of atoms either when a heavy one disintegrates or when two light ones join together.

Nuclear reactor A chamber containing nuclear fuel capable of producing a controlled chain reaction based on nuclear fission.

Nucleus The central core or kernel of an atom. The main mass of the atom is in the nucleus which consists of positively charged protons and neutrons without charge.

Particle accelerator An apparatus used for giving charged particles extremely high speeds. There are several different patterns. See cyclotron.

Proton One of the fundamental particles of the nucleus of an atom. It has approximately the same mass as that of the neutron, and 1,840 times the mass of an electron. It has one unit of positive electric charge.

Radiation The sending out of rays, waves, or even particles, e.g. alpha particles, beta particles, and gamma rays. It is usually applied to electromagnetic waves, e.g. radiant heat, light, and radio waves.

Radioactivity The spontaneous disintegration of unstable nuclei of atoms. Some radiation and/or particles are given out at the same time.

Radio-carbon An abbreviation for the radioactive isotope of carbon whose mass number is 14. Its half-life is about 5,500 years and this enables it to be used for dating buried forests and bones containing carbon.

Radium This is a heavy radioactive metal that continuously gives off alpha particles and in doing so changes to the inert gases radon and helium.

Transmutation The changing of one chemical element into another either naturally or artificially by bombarding atoms with high-speed heavy particles. Once the dream of alchemists but is now known to be taking place continuously in radioactive elements.

Uranium This is the heaviest natural element found. It is radioactive and continuously gives off alpha particles. There are several isotopes of uranium, one of which was used in the first nuclear bomb.

X-rays Electromagnetic radiation given off when electrons collide with solid objects. These rays affect a photographic plate. They can pass through objects that are opaque to light but the denser the object the more they are obstructed. This makes it possible to take an X-ray photograph of the bones inside the body of a living person.

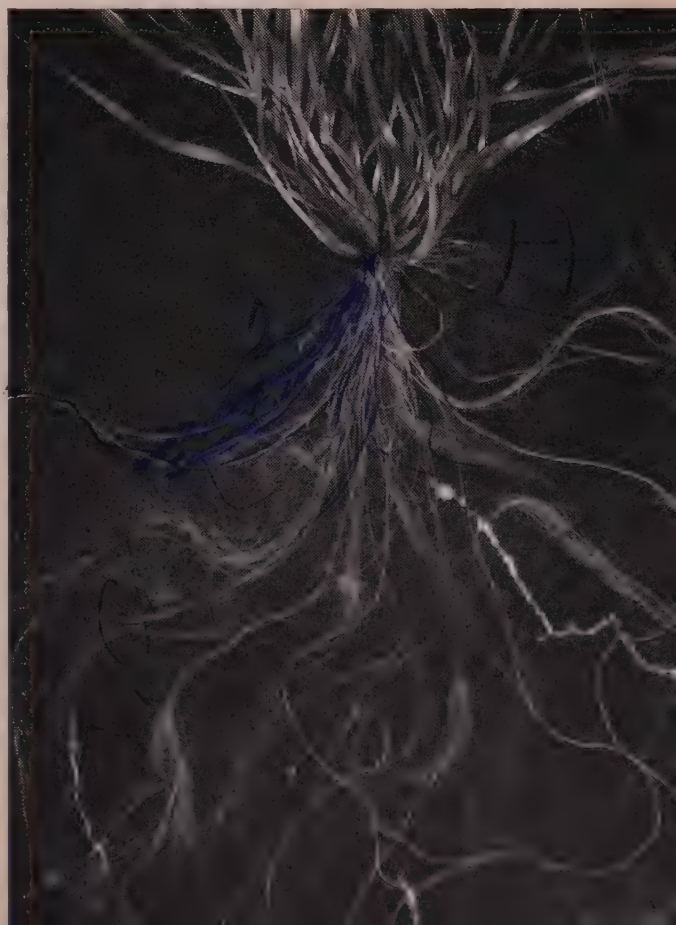
Problem A

What is matter made of?

There are many thousands of animals, vegetables, and minerals around us. Some of them appear to be made of the same matter but some are very different. Some grow and we say they are alive, others do not grow and appear to remain the same day after day.

The flesh and bones of our own bodies must certainly be made of the same matter as that found in the food we eat and drink. The branches of a tree and the fruit it produces are likely to contain the same matter as the gases it takes in through the pores in its leaves, called stomata, and as the liquids it draws up through its root hairs from the soil. The bricks we use to build our homes must contain the same matter as the clay that we find near the surface of the earth. The aluminium used to make our aircraft and our saucepans must be included in some way in the bauxite that we dig out of the ground, because it is from bauxite by an electrical process that aluminium is made. There are iron, sulphur, gold, copper, carbon, and very many more kinds of matter present in the ground below us.

Figure 1. Root hairs attached to the root of a grass plant.



When wood from the trees, and coal and oil from the ground are burnt, the fumes disappear into the air, so the air must contain some of the matter that was originally present in the products wood, coal, and oil.

It is therefore clear that all the time there is a great interchange taking place—some things are being produced and some things are being broken down. Matter, whatever it is made of, is continually changing

Figure 2. Most of the products of combustion from this bonfire pass into the surrounding air.

its pattern and its arrangement in order to create and to destroy. Man plays a large part in these changes as he brings many of them about by his activities and by his industry.

Scientists working with their delicate and expensive instruments have found that nearly all the different kinds of matter present in the earth are also present in the flaming white-hot gases surrounding the sun. In fact, so accurate was their work that some years ago they found one kind of matter in the sun that they had not found on earth. They called that helium after the Greek word *helios* meaning 'sun'. Some years later helium was found on earth and it proved to be a very light gas that would not burn. Immediately it was in great demand for filling airships and balloons. We shall learn more about this gas later in this book.

Figure 3. The flaming white-hot gases shooting off from a section of the surface of the sun are seen clearly during the short period of a total eclipse.

Partly because of these discoveries some scientists think that in some way, and nobody really knows how, the earth must have broken away from the sun. Other scientists think that the sun, and the earth, and all the other planets, and the stars, were formed by great clouds of gases whirling together and condensing into liquids and solids. There are other suggestions too, but, whatever the process was, we think that most of the different kinds of matter are to be found in all the celestial bodies. The wonder of the creation of the universe is, and may be for a very long time, one of our great mysteries. What is certain is that the master plan is a great mystery that is far from being unravelled.

Let us learn more of how men have attempted to find the pattern and design of the many kinds of matter. We have gone a long way in this investigation as we shall see, but there are very many problems still ahead of us which will strain the imaginations and the energies of even the most brilliant of our scientists. We may never know all the answers, but what we have discovered so far has enabled us to make some good guesses, and to see something of the connection between matter and energy.

Question A.1. Who were the first men to think of particles of matter?

The first men who began seriously to think about the way that matter is made were the ancient Greeks. A few of these people —the teachers and the thinkers of their nation—were called philosophers, which means lovers of knowledge. Although they did not possess scientific apparatus, such as we have today, to enable them to observe the very big things and the very small things,

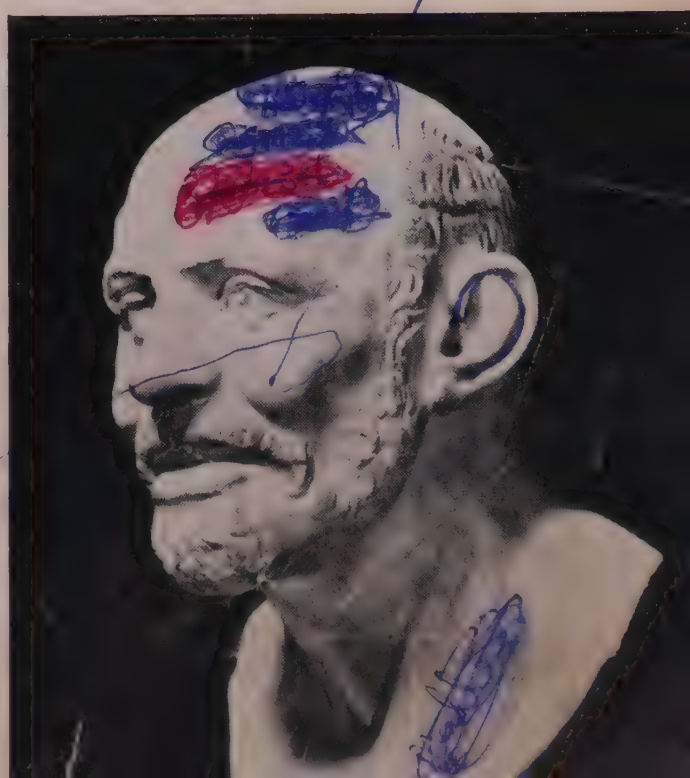


Figure 4. The Greek philosopher Democritus was the first man to think that matter consisted of atoms.

or to carry out experiments as we can, some were keen observers. Their brilliant and careful arguments helped them to understand and to make reasonable explanations of their everyday observations.

The Greek philosopher Democritus, who lived about 2,400 years ago, argued that if any lump of matter can be divided up into two smaller pieces, and each of the smaller pieces can be divided again into two smaller pieces still and so on, then a time will come when this process of division will cease and the final very tiny piece cannot be divided any further. He named these final pieces *atoma* which means 'indivisible', and it is from this Greek word that we get our word 'atom'. He said that everything that exists—men, animals, plants, minerals, the earth, the oceans, and the stars—are made up of millions of tiny particles all packed together like the crawling bees in a swarm or the moving grains of sand on a beach. These atoms, he argued, are really indivisible, indestructible building bricks of matter. They are extremely small, so small that they are invisible to the human eye. By arranging these building bricks in different ways different materials can be made. Empty space exists around the atoms and they are always in a state of movement. This was an amazing speculation, and, as we study further, we shall learn how advanced his ideas were.

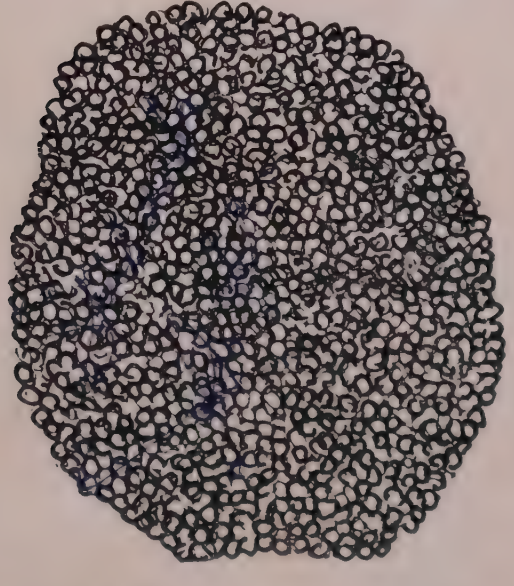


Figure 5. According to Democritus matter consisted of atoms packed closely together like grains of sand on a beach.

Unfortunately, not all the Greek philosophers agreed with him, and there were rival speculations. One that became popular was that the universe consisted of four basic elements 'earth, air, water, and fire'.

Democritus had a bitter rival in Aristotle, who was one of the most brilliant pupils of the great Greek philosopher Plato.

Aristotle opposed the theory of the atom as outlined by Democritus. He favoured the theory of the four basic elements and endeavoured to use it to explain such properties as dryness and damp, coldness and warmth. For most people the theory of Aristotle was easier to understand and this, combined with the great success he had in many branches of knowledge, made it seem futile to challenge his opinions. Thus it happened that Aristotle's ideas dominated scientific thinking for many centuries.

Figure 6. A statue of Aristotle in a museum in Rome.

We shall learn later how near our ideas of today are to the idea of the atoms as proposed by Democritus, and how completely wrong were the four basic elements as supported by Aristotle.

Figure 7. An alchemist at work in his laboratory.

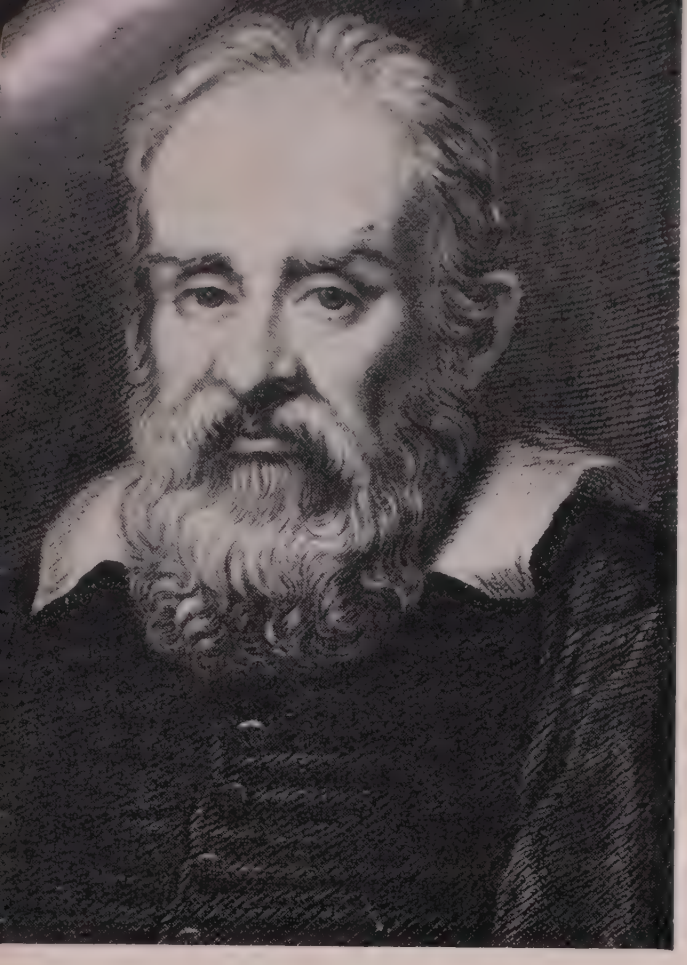


Figure 8. Galileo Galilei (1564–1642) supported the atomic theory of matter against the ideas which were popular during his lifetime.

Hundreds of years later the alchemists who hoped to turn lead and other base metals into gold were deceived from the beginning by following Aristotle's unsound and false ideas of the nature of matter. The scientist of today searches for the truth and is not willing to accept any theory that does not fit careful experimental observations. The alchemists failed because they did not act as true scientists; they accepted without question Aristotle's theory of the four basic elements 'earth, air, water, and fire'. However, they made great contributions to science by learning how to perform experiments, and how to make and record accurate observations.

It was a great day for science when in 1589 the young Italian scientist Galileo challenged the inaccurate ideas of Aristotle. In many instances this was done by carefully designed experiments and an accuracy of observation that could not be doubted. He was at the time immensely unpopular for having dared to dispute with the followers of Aristotle. Galileo brought to light once more the theory that matter was composed of atoms, and thus opened the way for those who followed to prove how nearly correct were the ideas of Democritus.

Question A.2. Who were the men whose experiments suggested the nature of matter?

Democritus had imagined atoms as being very small indivisible particles, but he had no idea what shape they were and neither had anybody else. As explained in the last question, scientists had paid no attention to these ideas for about 2,000 years from

the time they were first suggested. Then after the time of Galileo all kinds of guesses were made about their shape, but nobody had seen an atom. In 1590 Jansen had built a microscope, and about 1660 a Dutchman named Leeuwenhoek had made a more powerful microscope. Even with this instrument it was impossible to see one of these atoms.

During the years that followed, mainly because of the example set by the alchemists, much experimentation took place. Substances were examined chemically with extreme care and patience to discover which ones could neither be separated into other substances nor be built up from other substances. These substances were called 'simple' substances or *elements*. Those substances that were composed of two or more elements were called *compounds*. Robert Boyle, an Irishman working at Oxford and with the Royal Society in London, was the man who started the movement to find out what kinds of matter were elements. He concluded that on earth there existed only a limited number of elements. He also thought that some common substances like water were compounds, and others like air were composed of a *mixture* of elements and compounds.

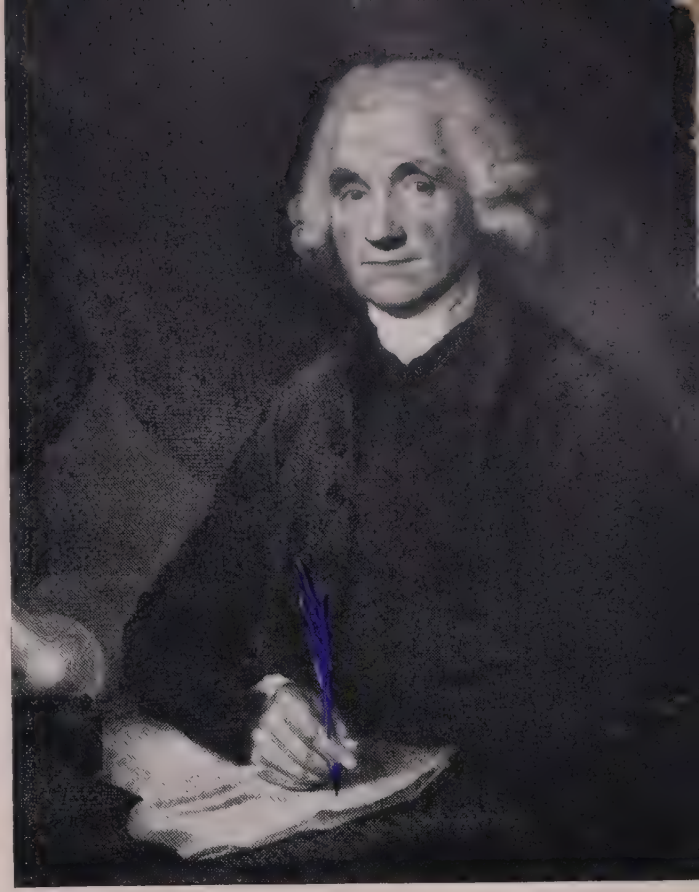


Figure 9. Joseph Priestley (1733–1804) was the nonconformist minister who discovered oxygen.

After Boyle had led the way, scientists from all over Europe began to find new elements. The Englishmen Cavendish and Priestley discovered hydrogen and oxygen; the Frenchman Lavoisier, nitrogen; and the Swede Scheele, chlorine. Boyle discovered that the solids gold, silver, sulphur, and phosphorus were elements. Hence an element could be either a solid, a liquid, or a gas. The gaseous elements had different properties, some had odour, some colour, and some were invisible. Two

of the gases, hydrogen and oxygen, combined to form the liquid water and, what was more exciting, every time they combined they did so in the same proportions—one part by weight of hydrogen with eight parts of oxygen. These proportions never varied and if one tried to make them combine in any other proportions there was always some of one of the gases left over. Also, when any two elements were combined to form a compound it was observed that they always did so in the same proportions.

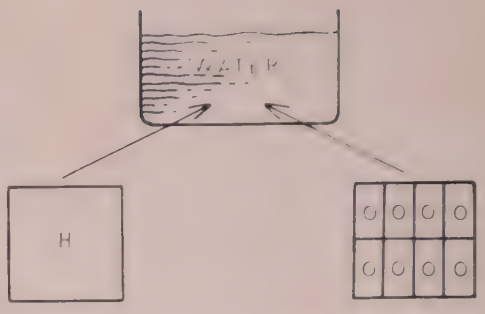


Figure 10. One part by weight of hydrogen combines with eight parts by weight of oxygen to form water.

Scientists made great advances during the 200 years after Galileo and indeed between the time Boyle was alive, and the early nineteenth century. It seemed that some regular pattern about the nature of elements was emerging from the mass of knowledge being collected as a result of the observations of many experiments.

Figure 11. John Dalton (1766–1844) was the chemist and schoolmaster who put forward the modern atomic theory which is the foundation of chemical theory.

It was the English chemist and schoolmaster John Dalton who put forward in 1808 a reasoned explanation of these observations in what has been known as his atomic theory of matter. He knew that every crystal of salt when seen under the microscope was similar to every other crystal of salt, and every crystal of sugar was similar to every other crystal of sugar. But salt and

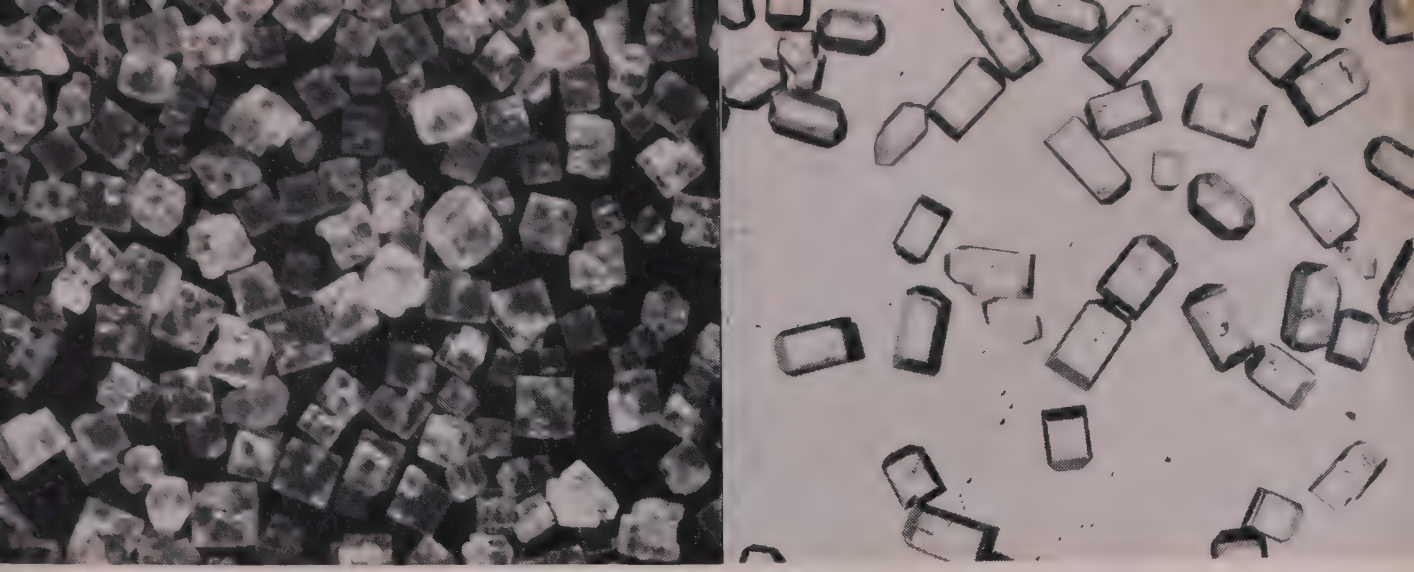


Figure 12. Crystals of salt (left) and sugar (right).

sugar crystals were different from one other. He knew also that ice, water, and steam were different forms of the same substance, and if the small individual particles were closely packed together the form was that of solid ice, if loosely packed they formed the liquid water, and if free to wander almost at will they spread out everywhere as the gas steam.

Dalton's atomic theory supposed that matter consisted of small particles similar to those suggested centuries before by Democritus, except that where Democritus thought of one kind of atom as the smallest indivisible particle of all sub-

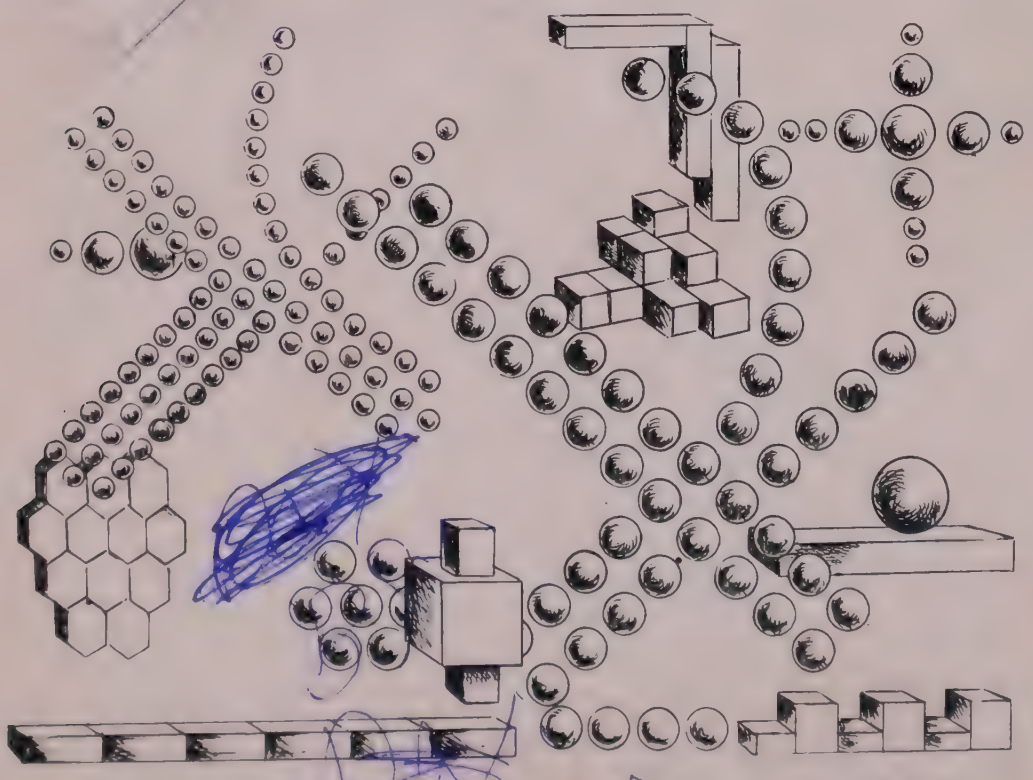


Figure 13. Atoms of different elements as imagined by Dalton.

stances, Dalton said that every element had its own particular kind of atom. The atom, as imagined by Dalton, was also indivisible and was the smallest particle of an element that could take part in a chemical reaction. An atom was like every other atom of the same element, and weighed the same, but it was unlike the atoms of other elements.

Dalton's atomic theory was adequate to make sense of all the facts then known about the elements. It was a tremendous step forward in the understanding of the nature of matter and served well for many years, enabling scientists to develop in a logical, practical, and accurate way the study of chemistry.

This investigation of the nature of matter reads like a detective story. As experiments were carried out, and clue after clue was unfolded, so the whole pattern became clear until, finally, there was no doubt that the small indivisible atoms were the building bricks responsible for the construction of all matter.

Question A.3. What is a molecule?

The atomic theory as proposed by Dalton did not tell us how many atoms took part in each chemical reaction, it simply gave the proportions by weight. In fact, Dalton assumed that water was composed of one atom of hydrogen and one atom

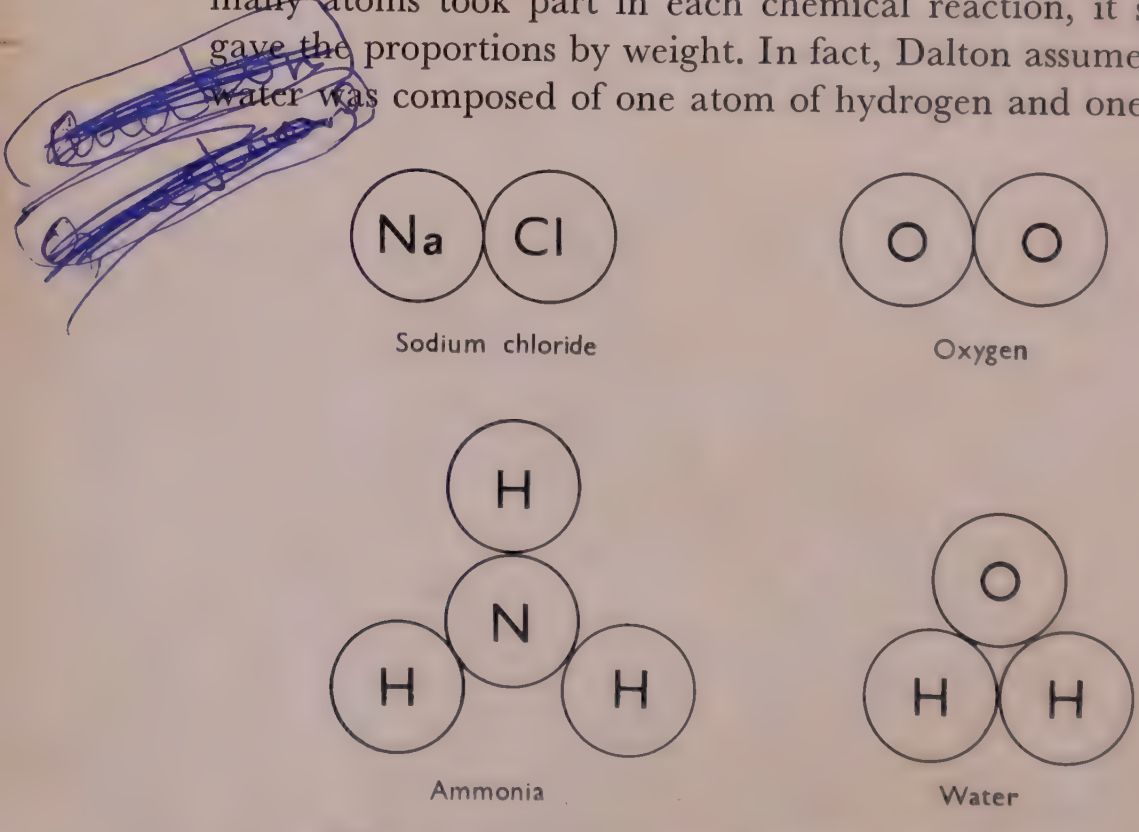


Figure 14. Molecules formed from two or more atoms.

of oxygen, and because experiments had shown that their weights were in the proportion of one for hydrogen and eight for oxygen it meant that the weight of an atom of oxygen was eight times that of a hydrogen atom. Nobody knew the real relative weights of the atoms and thus nobody knew how many atoms of hydrogen combined with how many atoms of oxygen to form the compound water. Thus the assumption made by Dalton might or might not be true.

The problem was solved by the Italian physicist Avogadro in 1811. He found, by experimental methods concerning the volume of the gases, that two atoms of hydrogen combined with one atom of oxygen to form water. Thus when water is formed from hydrogen and oxygen, one part by weight of hydrogen consists of two atoms and combines with eight parts by weight of oxygen consisting of one atom only. Hence each atom of oxygen weighs sixteen times as much as an atom of hydrogen.

Avogadro used the word *molecule* (a little bundle) to mean the particle that is formed when two or more atoms combine. For example, some atoms join with similar atoms to form 'tight little bundles', and in a free state they are always found moving about in this way. Hydrogen in its free state consists of molecules of two atoms each, and so does oxygen. An ammonia vapour molecule, however, contains a bundle of one nitrogen and three hydrogen atoms.

Chemists use symbols to represent atoms, molecules, and compounds. Equations show how chemical reactions take place. For example, one represents in the following way atoms of hydrogen, oxygen, and carbon—H, O, and C; a molecule of hydrogen, oxygen, and water—H_2, O_2, and H_2O.

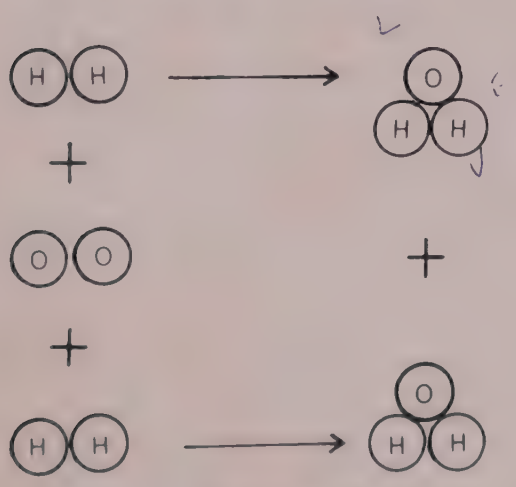


Figure 15. $H_2 + O_2 + H_2 = H_2O + H_2O$.

We have twice mentioned that hydrogen and oxygen combine to form water. They

do this with quite a considerable explosion which can be dangerous if the gases are in glass containers. This chemical reaction can be represented by drawing the molecules or by the equation:

$$2H_2 + O_2 = 2H_2O$$

The structure of matter is much more complex than Dalton thought and some compounds like ordinary cane sugar have

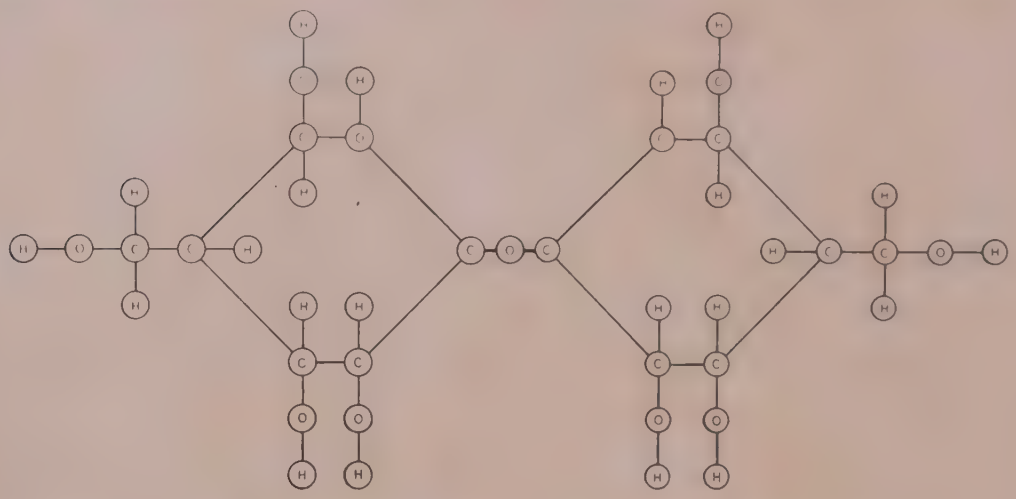


Figure 16. One way of representing a molecule of sugar: $C_{12}H_{22}O_{11}$.

as many as 45 atoms in a single molecule. There are 12 atoms of carbon (C), 22 of hydrogen (H), and 11 atoms of oxygen (O), so that it is expressed as $C_{12}H_{22}O_{11}$.

Men were now getting nearer to being able to discover what substances were made of. They knew at this period, about the middle of the nineteenth century, that matter consisted of elements and compounds. They already knew, of course, that these could be mixed together, not combined chemically together, to form mixtures. They knew too that elements could be made of a number of similar atoms or molecules, and that compounds were made of different atoms grouped together.

Some things to do

Atoms are so small and the apparatus needed to observe their effects is so costly that there are few practical things you can

do. You can, however, see some of the relevant experiments being performed by means of some excellent films, and you can also see some well-drawn animated impressions of what scientists imagine to be happening inside the atom.

Your best plan will be to use a library and to learn there from dictionaries, encyclopaedias, and many of the splendid books written on these subjects. Your teacher or the librarian will help you to select some of the appropriate books.

Your teacher will also help you to visit museums in your district, to see at school some of the moving films and filmstrips available concerning these subjects, and to arrange a display of the really splendid and colourful wallcharts and diagrams. Many of these are available on free loan and some of them can be hired or purchased.

The lists that follow give only a few of those that are produced. New material is constantly being prepared; your teacher knows how to find this new material and probably keeps a list of the most recent and useful additions. The various firms are always happy to supply up-to-date catalogues of their products.

1 Prepare a short talk to give to your class on the life of one of the following people. The other members of the class can choose another person to study and then you can all listen to all the talks. Democritus, Aristotle, the alchemists, Galileo, Boyle, Cavendish, Priestley, Lavoisier, Scheele, Dalton, and Avogadro.

2 Prepare a talk on one of these subjects and illustrate your talk by selecting certain frames (it is usually unnecessary to include all the frames) from some of the filmstrips mentioned below and any new ones your teacher knows about. Atoms, molecules, crystals, elements in the sun.

3 Learning from books. Read some of the books listed at the end of each section. Your teacher can probably make a first selection of the books that are likely to interest you.

4 Learning from films. See if your teacher can arrange for you to see any of the filmstrips listed.

5 Obtain a simple magnifying glass and examine many of the

small crystals of some common substances such as salt, sugar, washing soda, and copper sulphate.

Wallcharts

Select from *A Catalogue of Wallcharts* of the Educational Foundation for Visual Aids (E.F.V.A.), 33 Queen Anne Street, London W.1.

There is a series known as *Famous Scientists* supplied by E.F.V.A. which deserves a permanent place on the walls of your science room.

Educational Productions Ltd of 17 Denbigh Street, London S.W.1, supply the wallchart *The Atom*, No. C644/1.

Filmstrips

Educational Productions Ltd supply two useful filmstrips: *Atoms*, No. 5076, and *Molecules and 3 States of Matter*, No. 5206.

Books

D. M. DIAMOND and R. INNES. *Three Hundred Scientists*. Junior Club Publications Ltd

A. L. MANN and C. VIVIAN. *Famous Biologists*. Museum Press

G. DAWNEY. *Aristotle and Greek Science*. Chatto & Windus

I. BENDICK. *Archimedes and the Door of Science*. Chatto & Windus

R. MARCUS. *Galileo and Experimental Science*. Chatto & Windus

H. SOOTIN. *Robert Boyle, Founder of Modern Chemistry*. Chatto & Windus. (All four from the Series 'The Immortals of Science'.)

A History of Science and Technology, Part 1. Pelican

LUCRETIUS. *The Nature of the Universe*. Penguin Classics

M. NEURATH. *Inside the Atom*. Max Parrish

Oxford Junior Encyclopaedia, Vol. 5. Oxford University Press

Problem B

What do we imagine to be the structure of an atom?

The last problem described how the great scientists and thinkers during years of careful and logical argument followed by clever experimental work had uncovered the great secrets of the structure of matter. There had been setbacks and delays in plenty and many people who by their inability or unwillingness to resort to observation and experiment obstructed the progress of scientific discovery.

By the time Michael Faraday began his investigations concerning electricity in the years 1831–1834 the scientists were ready and eager to know more about the structure of the atom and asked if it was really a hard indivisible sphere as Dalton had imagined.

It was realised that the atom was very very small, and thus any attempt by the scientists to investigate its structure was immediately recognised as difficult. We know now that it would require more than a million, million, million atoms to fill the hole in a sheet of paper made by a single pinpoint—of course we cannot imagine such a small particle as an atom must be. To try to discover its structure seemed a hopeless task. Hence the only thing to do was to follow other lines of thought, to improve all the apparatus used, and to investigate carefully every strange observation that occurred.

Much progress was, in fact, made in other fields of science during the fifty years that followed the time when Dalton and Avogadro had put forward their suggestions concerning atoms and molecules. It was discovered that both atoms and molecules are always in a state of movement or vibration, covering short distances in solids, longer distances in liquids, and in gases travelling to the limits of the confining space. Many new elements were discovered, each one having its own particular type of atom.

Question B.1. Who first identified the electron?

It had been known since the days of the Greek merchant, mathematician, and astronomer Thales, that when amber was rubbed it was capable of attracting light objects like dust and small pieces of paper. The Greek word for amber is *elektron*, and it is this word that we now use and we spell it 'electron'. We all know of many other substances which when rubbed will not only attract light bodies but will actually produce visible sparks of electricity. A nylon shirt, for instance, will cling to your body and will create many sparks when it is quickly pulled off an undervest. It was found that these sparks could be led away along a copper wire and wires of several other metals.

Scientists also found that when certain similar bodies were rubbed they would repel one another, as two strips of polythene will if they are quickly pulled between two dry fingers. However, it was found that when various other pairs of

Figure 17. The attraction and repulsion between charged bodies. The charges on the hand and the polythene strip (left) attract each other, whereas the two similar charges on the two polythene strips (right) repel each other.

different bodies were rubbed and then brought together some of them repelled and some of them attracted each other.

Benjamin Franklin (1706–1790), an American scientist, collected some electricity from thunder clouds by flying a kite. He was lucky not to have been electrocuted! He is remembered because he came to the conclusion that there were two kinds of electricity, and he called them positive and negative. He also found out by experiment that bodies carrying opposite charges of electricity, one positive and one negative, attracted each other but if the charges were the same they repelled each other.

An Italian physicist Volta (1745–1827) invented in the year 1800 a continuous source of electricity, a cell made by dipping plates of copper and zinc in a salt solution. Volta mounted many of these pairs of plates in a 'pile' and found that this pile produced the same two kinds of electricity 'positive' and 'negative' as Franklin had found. Volta's work is remembered today by the word 'volt', meaning the unit of electrical pressure.

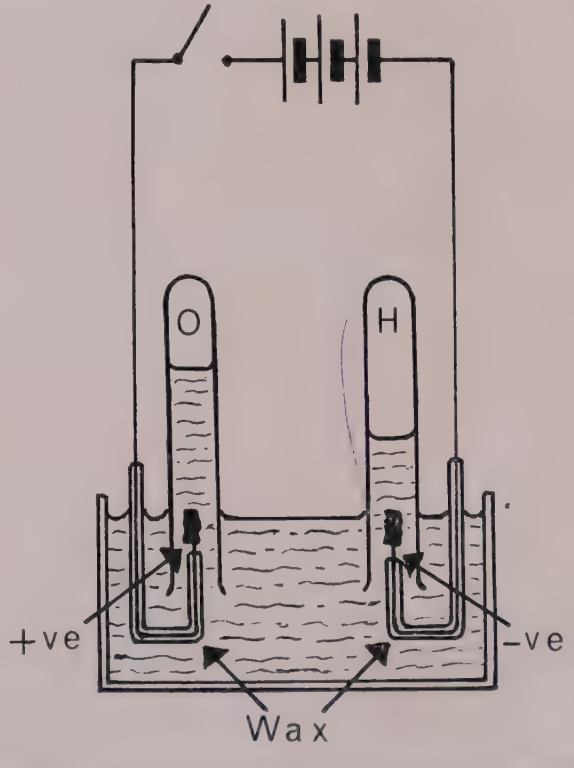


Figure 18. Water broken down by electricity into hydrogen at the cathode (−ve) and oxygen at the anode (+ve). The electrodes are small carbon plates and the connecting wires are insulated from the acidulated water by a coating of wax.

Franklin had been puzzled by these two kinds of electric charges and by the forces that appeared between them. He wondered if they had anything to do with the atoms themselves. He was not to know, because it was not until about 100 years after his death that the clue came from the following most startling experiment.

Water, made conducting by the addition of a drop of acid, was broken down into bubbles of hydrogen and bubbles of oxygen by the passage of an electric current. Electricity had separated the molecules of water into hydrogen and oxygen, it had somehow removed the forces holding the atoms together in the molecule. Since Dalton's time these forces had been one of the great mysteries—why was the combination of the atoms in a molecule so stable and so strong? From this day onwards it appeared to be owing to electricity.

Scientists then began to suspect that atoms in some way contained electric charges, but how could this be? Elements in their normal free state appear to have no charges at all because they do not repel or attract one another. If there were charges inside the atom, then there must be equal numbers of positive and negative charges. Was this yet another clue to the structure of the atom? In any case nobody knew what an electric charge was, although they knew some of the things it appeared to be able to do. They knew also that the electricity produced by chemical means as in the Voltaic pile was the same as that produced by rubbing things together.

Scientists were progressing rapidly, but each step forward seemed to present more and more questions that called for answers.

The next tremendous step forward came, as so often before, from the careful observation of some carefully planned experiments. This time they were devised by an English scientist,

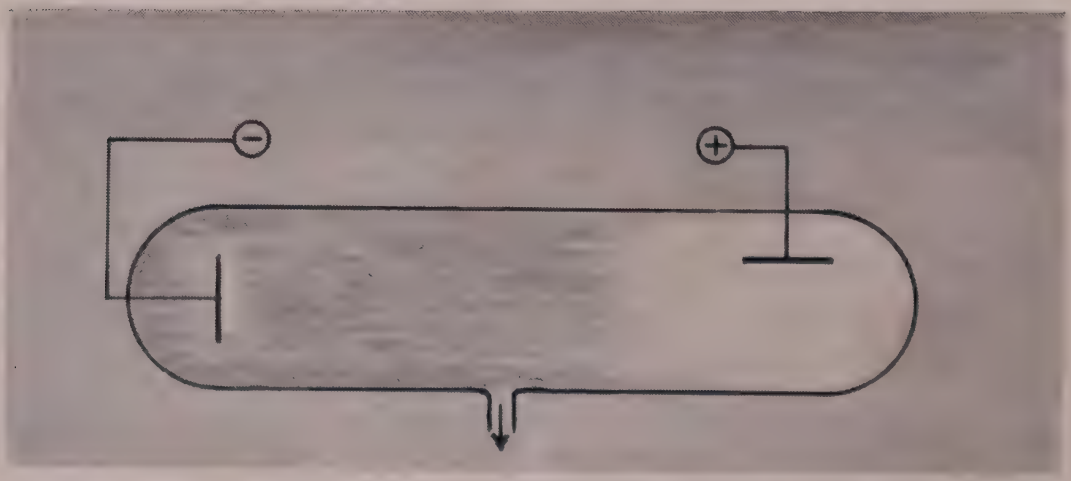
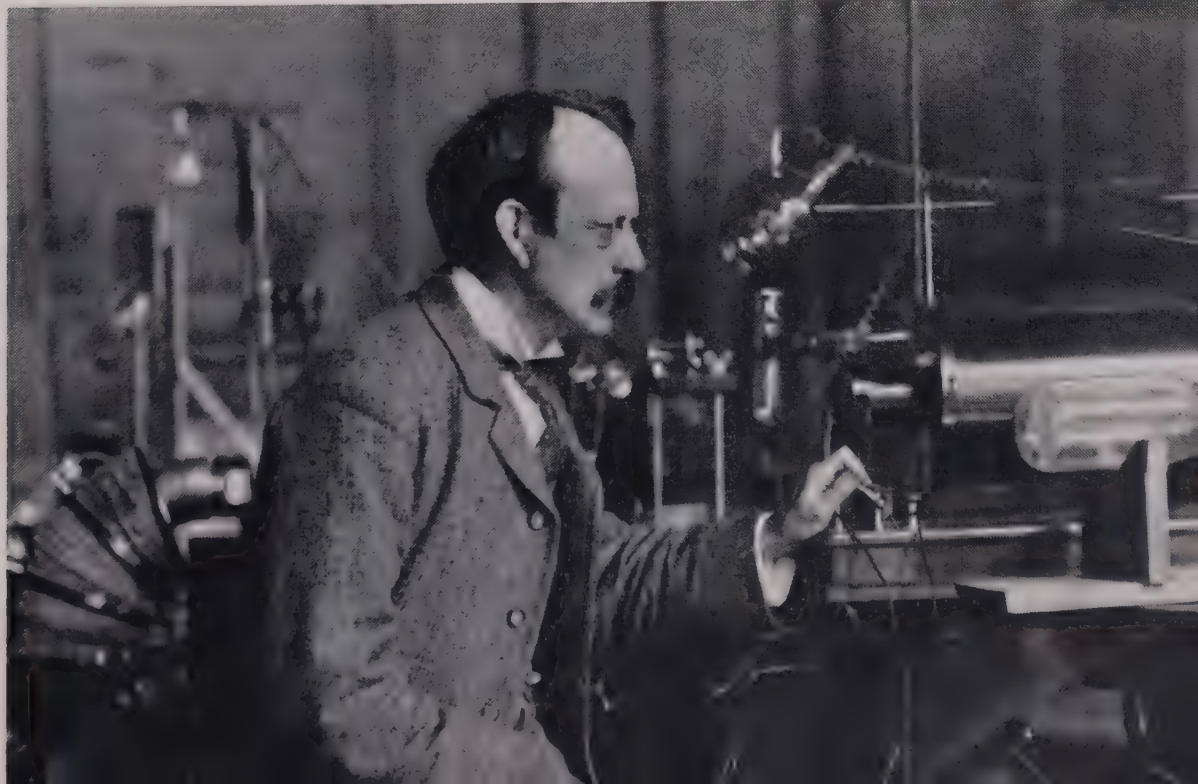


Figure 19. The glow produced at one end of a glass tube by an electric current passing through rarefied air.

J. J. Thomson, in the Cavendish laboratory at Cambridge in 1897. He made some quite unexpected observations when he passed a small electric current between two metal plates situated at the ends of a long glass tube from which the air had nearly all been drawn out. He noticed a strange glow on the glass at one end of the tube. He moved the plate at that end to one side and then the glow covered all the wall at that end as if something was being shot along the tube and was hitting the wall.

Thomson soon found that something was indeed being shot along the tube and this something could be bent when a magnet was brought up close to the tube. He knew that ordinary light was not bent by a magnet and from the direction of bending he discovered that it could be particles carrying negative charges of electricity similar to those Franklin had found a hundred years earlier. These particles were found to start at the metal plate connected to the negative pole of the battery, called the cathode, and hence were named *cathode rays*. Thomson was able by further brilliant experiments to determine that each of these particles had a definite charge and a definite mass, and found also that these particles were the same whatever the metal plate was made of. In fact, it

Figure 20. J. J. Thomson (1856–1940) by his discovery of the electron led the way to the electrical theory of the atom.



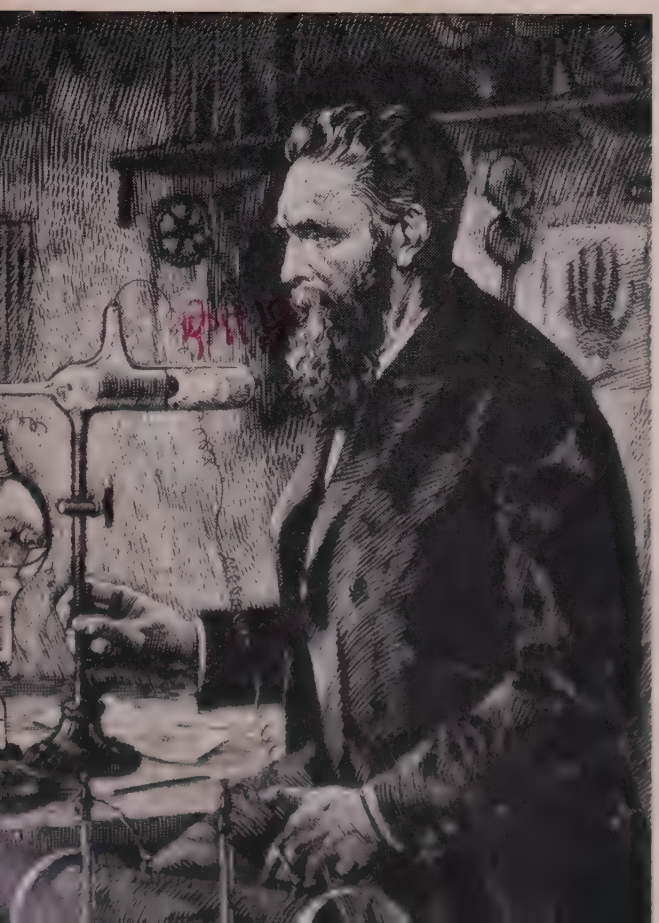
became clear that all atoms contained one or more of these particles. Such a particle was named an *electron*.

These discoveries made by Thomson opened up a whole new chapter in the search for the structure of the atom. He showed that 'electrons' existed and that they were lighter than hydrogen which was the lightest atom then known. So the atoms of Democritus and the atoms described by Dalton were after all not tiny indivisible solid spheres as scientists had imagined for centuries but they contained 'electrons'. Perhaps there were other particles also inside the atom? What exciting news this was! No wonder Thomson was awarded the Nobel prize (in 1906) and became President of the Royal Society. He was certainly the founder of modern atomic physics, and is often called 'the father of the electron'.

Question B.2. What is the importance of the discovery of X-rays and radioactivity?

Whilst Thomson in England was discovering the existence of electrons in atoms, in Germany and France other scientists were making extremely important discoveries that were to lead further in the understanding of the structure of the atom.

Figure 21. W. K. Röntgen (1845–1923) was the German physicist who discovered some strange rays and named them X-rays.



The German physicist Röntgen by good chance in 1895 happened to be working with a tube in the same manner as Thomson. Röntgen noticed that a screen covered with a certain chemical glowed in a dark room even when his tube was covered with black cardboard. Like all good scientists, he was observant and curious, and tried a number of simple experiments to find out more about the glow caused by these unknown or X-rays as he called them.

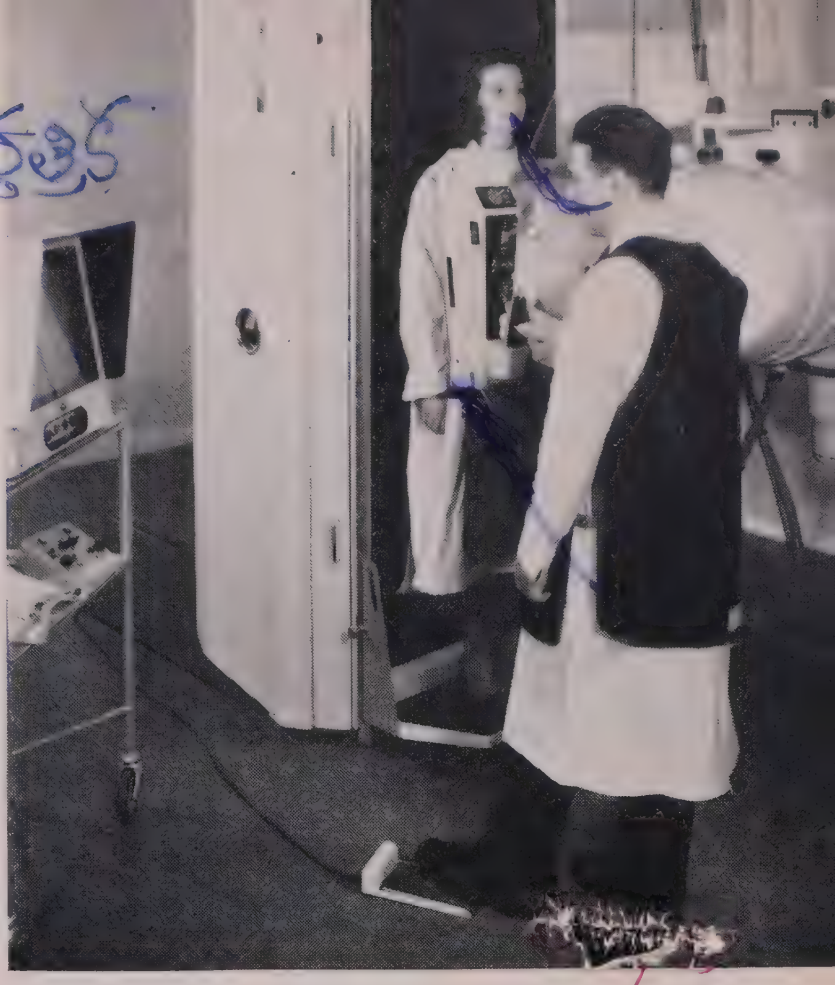


Figure 22. This person is having an X-ray examination of her chest. The operator is wearing a protective apron and he is observing the X-ray photograph on the screen at the left.

Röntgen found that X-rays could not be deflected by a magnet like Thomson's cathode rays or electrons were. Thus they were not charged particles. He found also that these X-rays would pass through light bodies like flesh but were stopped by dense substances like bones and metals. It was not long before machines producing X-rays were installed in hospitals to help in 'seeing' the fractures in broken bones and the shape of the internal organs of the human body without the use of surgery. X-rays are capable of blackening a photographic plate. They are produced where the cathode rays or electrons hit atoms. We now know more about these X-rays than Röntgen did—we know that fast-moving electrons in a discharge tube penetrate far inside the atoms where some of their kinetic energy is transformed into the energy of the X-rays given off.

The importance of these X-rays to the unfolding of the structure of the atom was not at first recognised by scientists. It was only revealed many years later, in 1913, when a young and promising Oxford student named Henry Moseley made an important discovery. He had considerable success when

bombarding various elements with electrons and found that the X-rays produced could be associated with a certain number for each element. This number was called the *atomic number* of the element and was found also to be the number of electrons in an uncharged atom of the element. This discovery enabled scientists to correct several of the peculiarities that appeared to be present in the table of elements as prepared in 1872 by the Russian chemist Dmitri Mendeleev. It is said that Mendeleev had a dream about how he could arrange all the elements then known in some kind of order that would show their chemical properties. His table, corrected now by Moseley, has been and still is that which brings order into what was a chaotic and unmethodical list of the properties of the elements. Unfortunately Moseley was killed in action in Gallipoli two years later and thus science was robbed of someone who might have been one of its brightest workers.

Becquerel (1788–1878), a French physicist, had been interested for some years in *uranium* (which was a relatively unknown element at that time) because it showed some of the same properties as Röntgen's X-rays. It had an effect upon a photographic plate and caused a slight glow when mixed with some other salts. Becquerel investigated these strange observations and discovered that uranium salts gave off X-rays without any apparent reason for doing so.

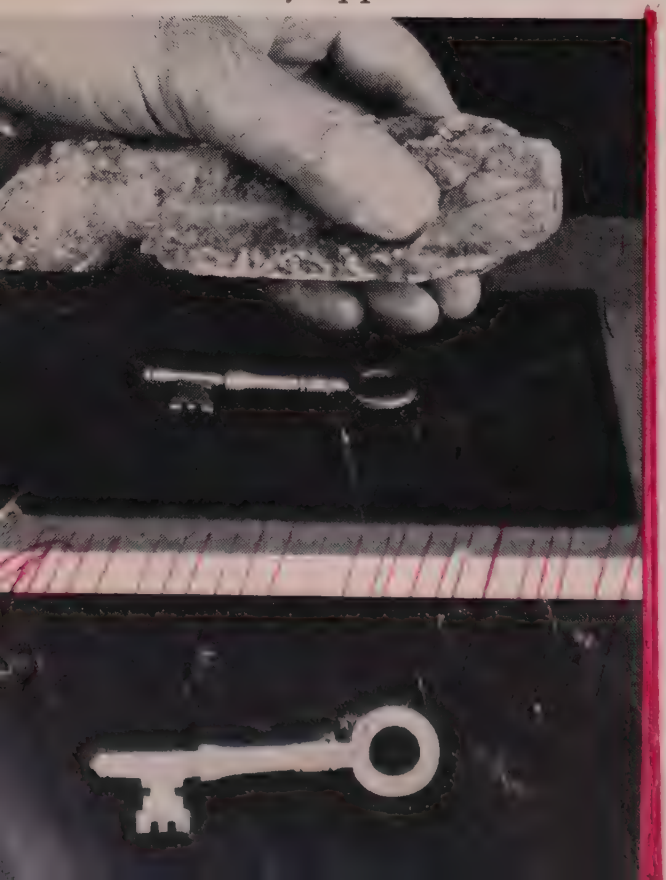


Figure 23. The key shown in the upper photograph was laid on a photographic plate wrapped in black paper, and a lump of uranium ore placed over it. After some time the plate was developed and on it was a 'shadow' of the key as seen below. Some rays had obviously been radiated from the uranium which were stopped by the metal key.

Figure 24. Pierre and Marie Curie at work in their laboratory

Both Röntgen and Becquerel by their keen observations and by their curiosity and ability to experiment made useful contributions to the discovery of radioactivity that followed. In fact, without knowing it, Becquerel had discovered what we now call *radioactivity*. But it was not until several years later that it was realised that he was seeing the effects of the energy liberated as the interior of an atom was breaking into pieces.

Becquerel observed also that there were other minerals that gave off similar rays. The search for a sufficient quantity of these minerals is probably one of the most dramatic and arduous in the whole history of science. It required enormous energy, endurance, and patience on the part of the Frenchman Pierre Curie and his wife Marie in 1898 to sort out and refine over a ton of selected ore to produce a few crystals

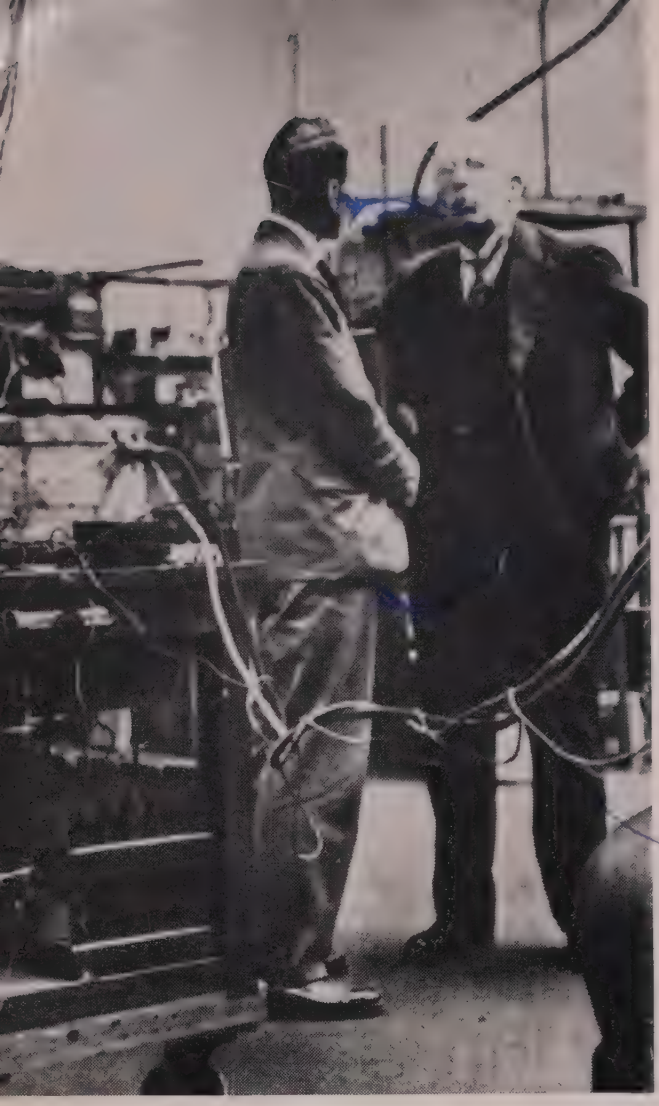


Figure 25. Ernest Rutherford (1871–1937) discovered and named alpha, beta, and gamma rays and later suggested a divisible nuclear atom which is often called 'the Rutherford atom'.

of some substance that gave off rays even more powerful than those from uranium. Marie Curie called this *polonium* after her native Poland.

After two more years' hard work the Curies found in the mineral ores from a mine in Bohemia another element which emitted such powerful rays that Becquerel in carrying a little of it in his pocket was severely burnt. The Curies called this element *radium*, meaning the shining element, and to the whole effect they gave the name radioactivity.

For several years there followed much experimentation to find out more about this radioactivity. A New Zealand physicist Ernest Rutherford, working under Thomson in the Cavendish laboratory at Cambridge, studied the radiations from uranium salts and made great discoveries. He found and named two types of radiation—those rays that only penetrated

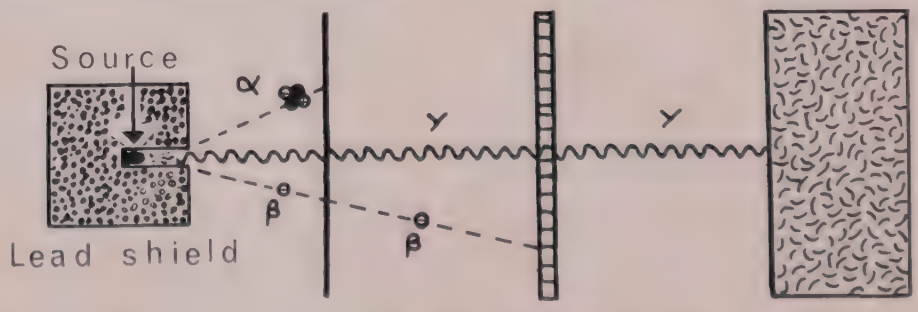


Figure 26. Penetrative powers of radioactive radiation. The radioactive source contained in the thick lead shield emits α rays which are stopped by a thin aluminium foil, β rays stopped by a thick aluminium sheet, and γ rays that require a thick lead block to stop them.

a short distance in air he named alpha (α) rays, and those that travelled much farther beta (β) rays. These α and β rays were not rays of energy like the X-rays.

When he caused these rays to pass through an electric field which he obtained between two oppositely charged plates, he noticed that the rays were deflected. Because of this observation he thought that they must be electrically charged particles.

At the same time another type of radiation was soon found to be present. This radiation consisted of rays that were called gamma (γ) rays.

The drawing shows how we can imagine these rays are bent in an electric field as they are shot out of a radioactive substance, such as the element radium. The radium must be kept in a thick lead shield provided with a small hole. The alpha rays are bent one way, the beta rays the opposite way, and the gamma rays are undisturbed by the electric field.

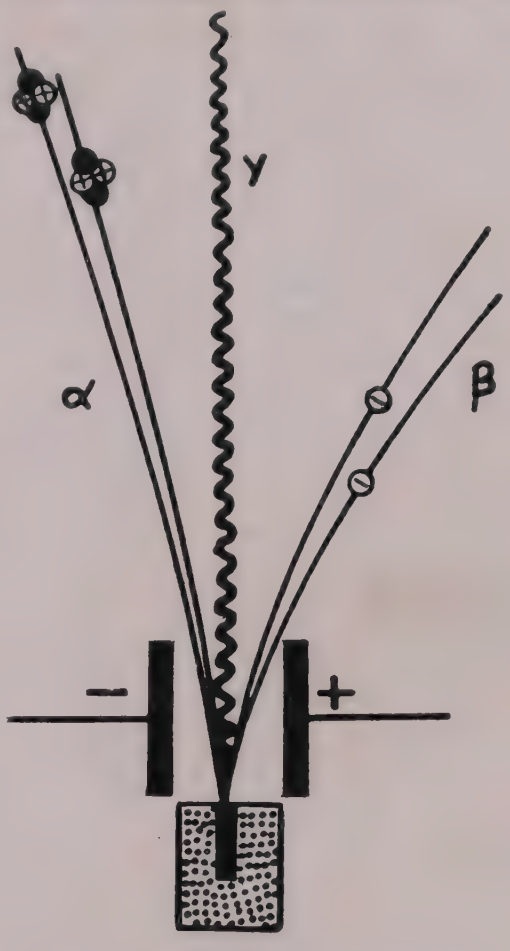


Figure 27. Radioactive radiation from a shielded source passing through an electric field produced between two plates connected to an electric battery. The gamma rays are projected forward undisturbed, whereas the alpha and beta particles are bent in opposite directions. The beta particles are more vigorously bent than the alpha particles.

Rutherford thus provided us with some important knowledge about the particles thrown out of an atom when it disintegrates—some must carry positive charges, some must carry negative charges, and others (the gamma rays) must have no charge.

At this stage it was clear to scientists that alpha and beta particles were included in the structure of the atoms investigated

and that somehow or other these particles leave the atoms of certain elements. In the case of some of the elements, when these particles break away from the atoms, radiant energy in the form of gamma rays is emitted.

Much more remained to be found out about the interior of the atom, but men and women were certain that scientists were working on a problem which one day would be solved. It was not a hopeless task!

Question B.3. What can we learn from a study of radioactivity?

Rutherford and one of his students named Soddy tried to understand the amazing facts about radioactivity. So far they knew that the alpha and beta rays were particles and that the gamma rays were radiations of energy. The experiments they performed proved conclusively that the beta rays were composed of electrons moving very rapidly, and that the gamma rays were similar to the X-rays but had a higher frequency and a shorter wavelength.

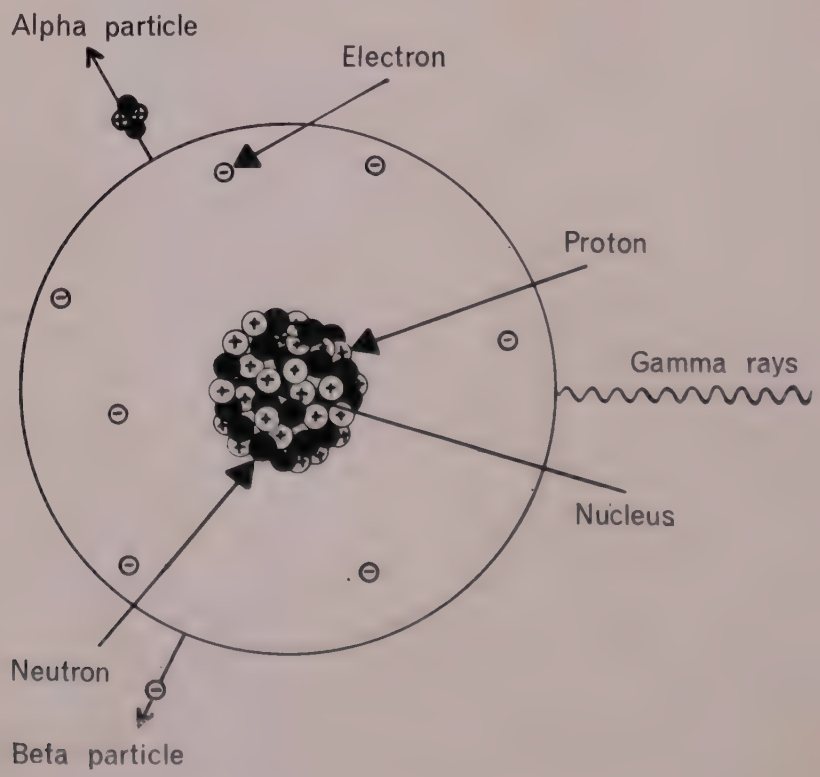


Figure 28. A radioactive atom.

It was the alpha particles that puzzled these two scientists for they were something quite new. They used experiments, that were by this time well tried at the Cavendish laboratory, and eventually discovered that these alpha particles were very heavy (about 7,000 times as heavy as an electron), that they moved relatively slowly, and that they carried a positive electric charge. They were able to capture the alpha particles and then made the astounding discovery that each had the same mass as a helium atom (refer to page 35) but its charge was equal to that of a helium atom which had lost two electrons. Thus they concluded that the alpha particles were parts of helium atoms.

Rutherford explained that radium disintegrates without any outside help, forming an alpha particle and a new element called *radon*. This idea of one element changing into another, known as *transmutation*, was not new but it now provoked much speculation. The particular kind of transmutation that the alchemists had been looking for was the turning of the baser metals into gold—something that has not yet been achieved.

It was next discovered that disintegration continued step by step in the case of uranium until a stable form of lead remained. You will learn later why some of these new elements have the same chemical name—they are isotopes of these elements.

At each of the steps in this

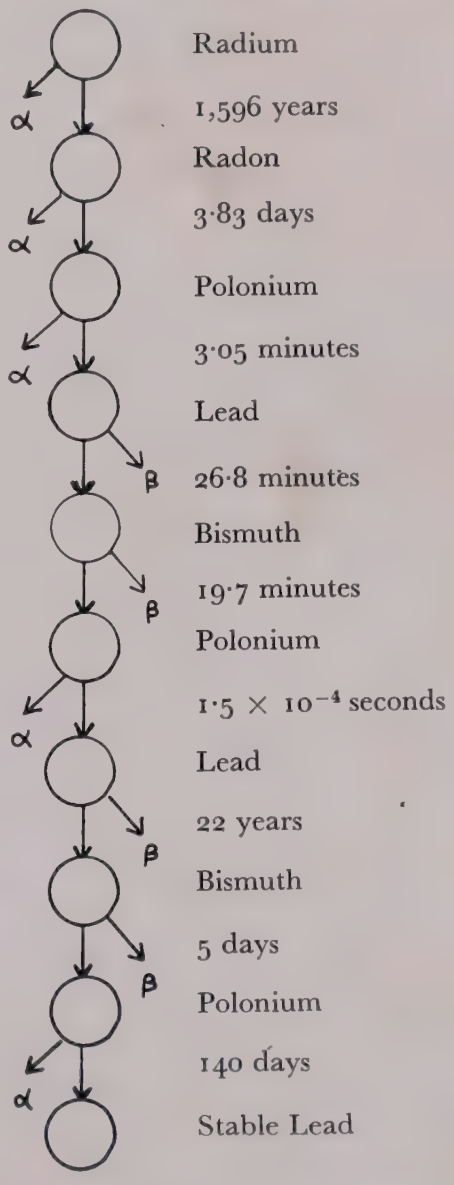


Figure 29. Some of the steps in the transmutation of uranium to stable lead. The common names of the intermediate products and the half-life of each one are shown.

transmutation an alpha or a beta particle is thrown out as each new element is produced.

The time taken for half of any given quantity of an element to disintegrate is known as its *half-life*. The half-lives of some of the elements in the transmutation from uranium to stable lead are shown in the drawing. These values for the half-life of the various elements are definite and well confirmed. They do not vary and that of uranium is 5,000 years.

By chemical analysis it has been possible to determine the amount of lead present in rocks containing uranium. Knowing the amount of lead and the half-life of the elements in the chain of disintegration we can make an estimate of the age of these rocks. This is the most accurate value we can obtain so far and it tells us that the age of the oldest rocks on earth is about 3,000 million years.

What changes we have seen in this unfolding story of the structure of matter! Once we thought that matter consisted of small indivisible particles, called atoms, and now we know that certain atoms break up on their own account. There must be considerable stores of energy in the atom because the radioactive atoms shoot out heavy alpha particles, high-speed electrons, and energy in the form of gamma rays. As the atom is so minute, a small quantity of matter will contain an enormous number of atoms, and therefore the energy available if it can be released must be tremendous. Indeed we now know that the energy is so large that one single gram of matter is sufficient to supply the electrical energy needed to floodlight a football stadium continuously day and night for a hundred years!

Question B.4. How was the structure of the nucleus of an atom found?

Dalton's idea that the atom was a small solid sphere was overthrown by Thomson, who found electrons inside the atom, and Rutherford, who found alpha particles in some of the atoms. The problem then was to discover how these were arranged inside the atom. The alpha particles were extremely heavy and each carried two units of positive charge. The

electrons each carried one unit of negative charge and were almost weightless.

With another extremely brilliant hunch Rutherford devised an experiment during which he bombarded a number of gold atoms (in the form of a thin gold foil) with a stream of alpha particles. He erected fluorescent screens in different positions around the foil and examined the screens for signs of alpha

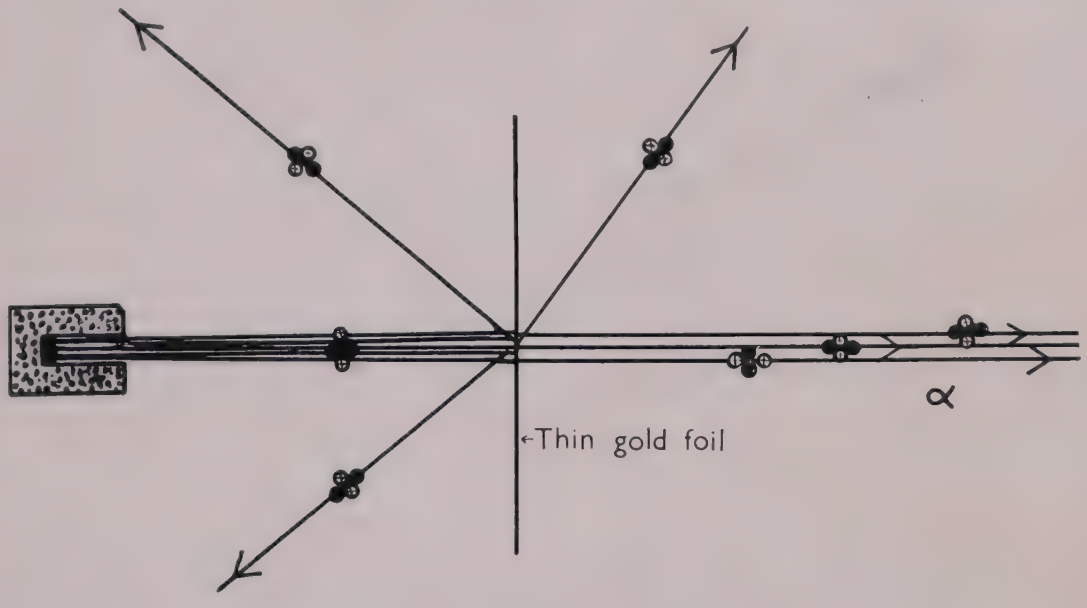


Figure 30. Alpha particles from the source partially surrounded by a thick lead shield are directed at the thin gold foil. Most pass straight through but about 1 in 8,000 is scattered as shown.

particles hitting them. He observed some interesting results—most of the alpha particles passed through the gold atoms as if they were empty spaces but a very few here and there were bent and even reflected back to the fluorescent screens. From these observations he deduced that the heavy positive particles in the atom were concentrated close together in what he termed the *nucleus* of the atom.

Rutherford with his assistant, a Danish scientist named Niels Bohr (1885–1962), suggested that the negatively charged electrons were spinning rapidly around this nucleus in very large distant orbits in well-defined positions or 'shells'. The electrons spin so rapidly that they resemble a solid wall, in the same way as do the spokes of a spinning bicycle wheel. The force of attraction created by the opposite charges of the

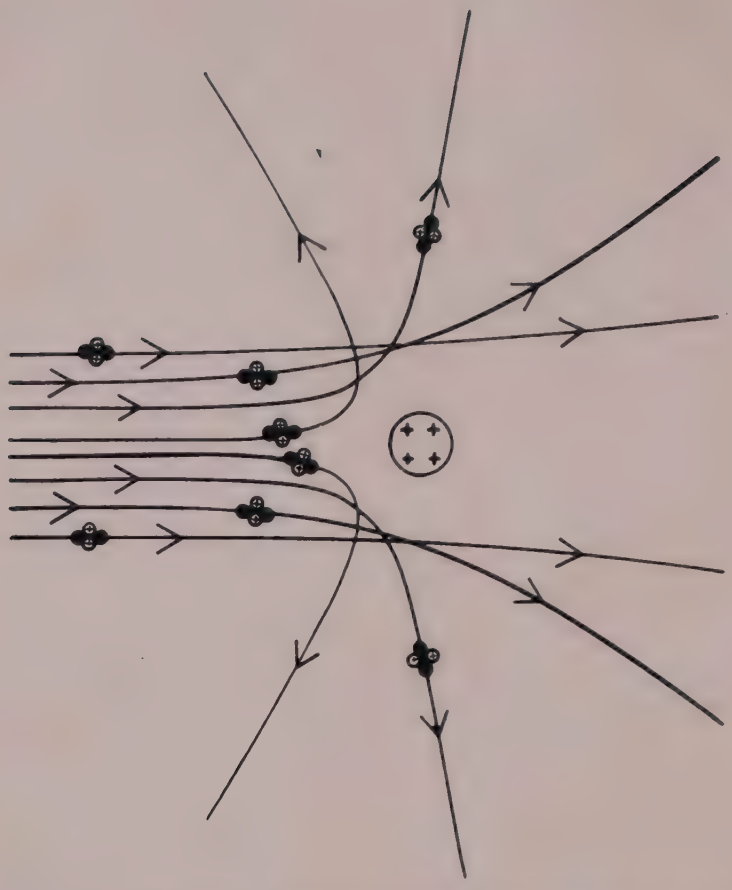


Figure 31. How Rutherford imagined the scattering of alpha particles took place close to the very small nucleus of the gold atom. The space where this takes place near the nucleus is unoccupied.

nucleus and the electron keeps them from flying apart. According to the calculations they made, the nucleus is about 50,000 times smaller than the orbit of the electron. You can picture how big the vast empty space inside the atom is if you compare the nucleus with a golf ball and then the relative size of the orbit can be compared with the size of a large football stadium. No wonder that so many alpha particles passed through the atom undisturbed.

Rutherford then bombarded nitrogen gas with alpha particles derived from radium and found that positively charged particles each having the same mass as a hydrogen atom were thrown out. These were called *protons* and each had one unit of positive charge only. Rutherford had produced hydrogen by bombarding nitrogen. Another transmutation!

Thomson, knowing that the total electric charge of every uncharged stable atom must be zero, suggested that an atom

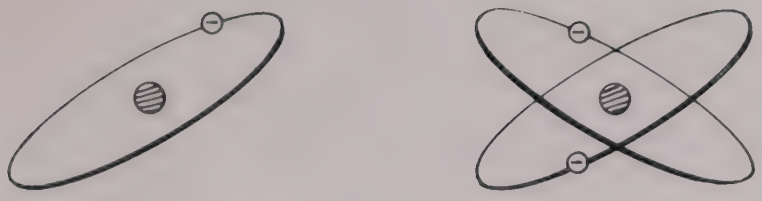


Figure 32. Hydrogen and helium atoms according to the orbital theory for the electrons proposed by Rutherford and Bohr.

of hydrogen, the lightest atom of all, consisted simply of one proton in its nucleus and one electron spinning round in an orbit.

Let us now think what all this means and see how well it fits the facts we know about the charges and masses of atoms.

Each proton has 1 unit of positive charge and 1 unit of mass.
Each electron has 1 unit of negative charge and negligible mass.

A hydrogen atom has no electric charge and 1 unit of mass due to the proton in its nucleus.

These seem sensible suggestions and agree with what we know about hydrogen. How does our knowledge of the helium atom fit in with these suggestions?

Scientists found that the atom of helium had 4 units of mass and they were able to determine this accurately. They also knew that the alpha particles were parts of helium atoms and that they had 2 units of positive charge and 4 units of mass. The 2 units of positive charge would account for 2 protons and thus 2 units of mass. Where were the other 2 units of mass unaccounted for? This was a difficulty that was not solved for several years until one of Rutherford's students, an Englishman, James Chadwick, in 1932 discovered another particle that had the same mass as a proton but was electrically

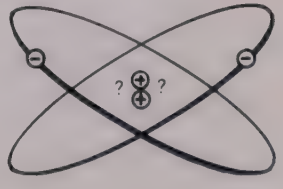


Figure 33. The puzzle of the helium atom. There are 2 electrons in orbit, 2 protons in the nucleus but the nucleus has a total of 4 units of mass.

neutral. This he called a *neutron*. The nucleus of a helium atom was then assumed to contain two protons and two neutrons. The existence of the neutron in the helium nucleus gave it the required 4 units of mass and satisfied what was known of the helium atom.

Each neutron has no charge and 1 unit of mass.

The nuclei of the other heavier atoms are supposed to consist of various numbers of protons and neutrons held tightly together.

Question B.5. What is the probable structure of an atom?

Thomson, and later Rutherford, from experimental evidence concluded that the simplest atom is the hydrogen atom, having one proton in the nucleus and one electron in orbit. Hydrogen is the lightest gas known. It is not surprising that many scientists think that the hydrogen nucleus, a proton, is a fundamental building brick in the structure of all other atoms.

It seems reasonable to suppose that we can now build up the structure of atoms by using all the particles we have discovered. There are always the same number of protons as electrons in a neutral atom. When there are also neutrons in the nucleus the mass of the atom is increased without altering the electric charge. When an electron is added to an atom the total mass is very little increased because the mass of an electron can be ignored when compared with the mass of a proton or a neutron. The proton and the neutron have each the same mass and this is about 1,840 times greater than the mass of an electron.

The whole mass of an atom can therefore be considered to be concentrated in the nucleus. The number of protons and neutrons in the nucleus thus determines its mass and this is known as its *mass number*.

The number of protons alone, or in the case of a neutral atom the number of electrons, is called the *atomic number*. This,

as we described earlier, was due to the work of Moseley in 1913.

We suppose therefore that the atom consists of a nucleus of protons and neutrons with electrons spinning in very large orbits around the nucleus.

In the drawings that follow on page 35 we can study how atoms are built up with these three particles. Below the drawing of each atom is written its name, symbol, atomic number, and mass number.

In order to make the drawings clear, the scale of the nucleus has been exaggerated as compared with that of the whole atom. Even so it is impossible to draw all the protons and neutrons separately and thus they are represented by number and the capital letters P and N.

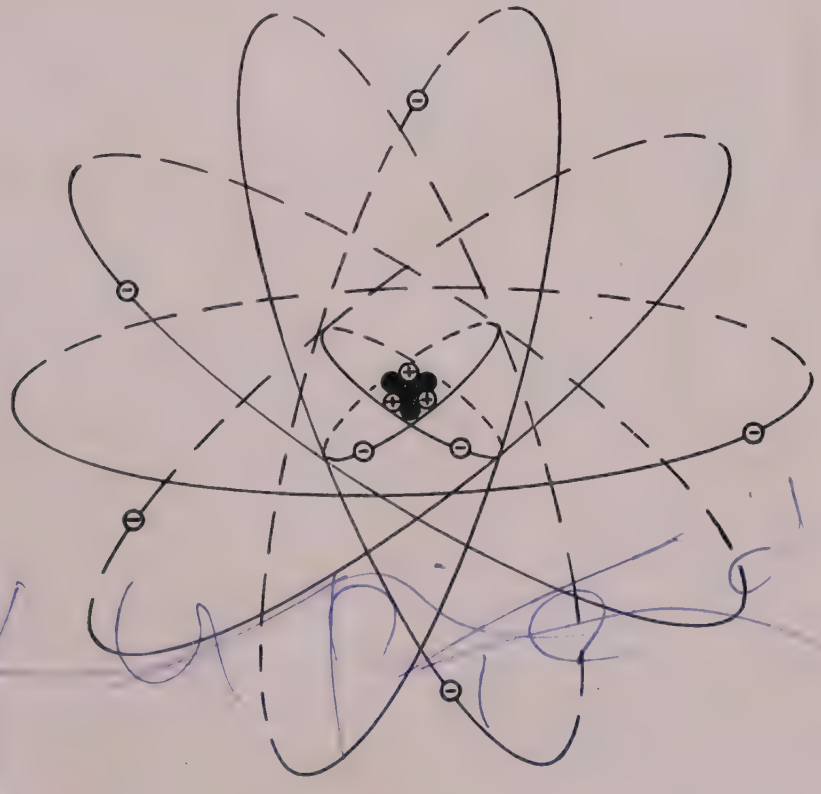
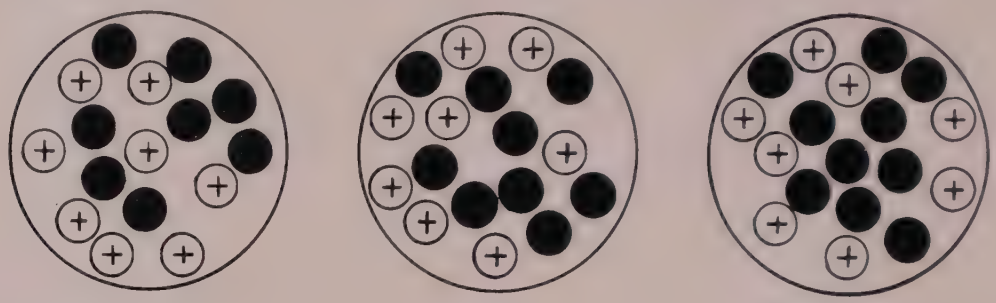


Figure 34. The nitrogen atom.

The electrons have been drawn for simplicity as if they were spinning round in flat orbits in their shells, but this is not so. They move in orbits sloping at various angles and in order to try to show this the nitrogen atom has been drawn here as it could look in the solid form.

We have only drawn the atoms as far as the inert gas *argon*, whose atomic number is 18, because the atoms are getting more and more complicated and crowded. It would soon get too confusing if the list were continued.

The drawings of the atoms on the first line of page 35 show three different structures having an atomic number of 1. They have one proton and one electron each but in addition they have either no neutrons or one or two neutrons in the nucleus. Atoms that have different numbers of neutrons but



8 Protons
8 Neutrons

8 Protons
9 Neutrons

8 Protons
10 Neutrons

Figure 35. The nuclei of the atoms of three isotopes of oxygen.

the same number of protons in the nucleus are called *isotopes*. The word isotope comes from the Greek words *iso* meaning same and *topos* meaning place. The first three drawings are isotopes of hydrogen, the next two are isotopes of helium.

The chemical properties of an element are determined solely by the number of electrons in the orbits in the atoms of the element. Thus all the isotopes of an element, because they have the same number of electrons as protons in their atoms, are *chemically alike*. It is therefore the *atomic number* which indicates the *chemical properties* of an element. The only difference between isotopes is in the number of neutrons in the nucleus and this is indicated by their different mass numbers. They are, in fact, so much alike that it is difficult to distinguish between them or separate them. As they are usually found together in nature they are not easily discovered and for many years their existence was entirely unknown. Only by making use of the difference in their physical properties can they be separated.

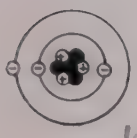
Hydrogen H
Atomic no. 1
Mass no. 1

Deuterium D
Atomic no. 1
Mass no. 2

Tritium T
Atomic no. 1
Mass no. 3

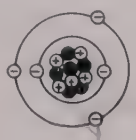
Light Helium
Atomic no. 2
Mass no. 3

Helium He
Atomic no. 2
Mass no. 4



Lithium Li
Atomic number 3
Mass number 7

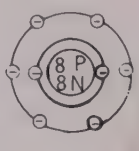
Beryllium Be
Atomic number 4
Mass number 9



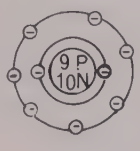
Boron B
Atomic number 5
Mass number 11

Carbon C
Atomic number 6
Mass number 12

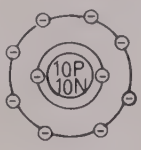
Nitrogen N
Atomic number 7
Mass number 14



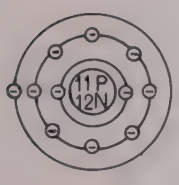
Oxygen O
Atomic number 8
Mass number 16



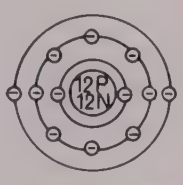
Fluorine F
Atomic number 9
Mass number 19



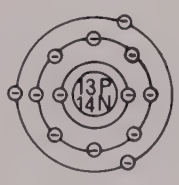
Neon Ne
Atomic number 10
Mass number 20



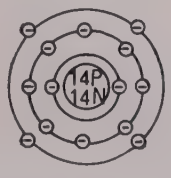
Sodium Na
Atomic no. 11
Mass number 23



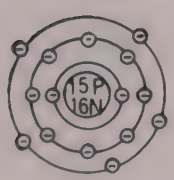
Magnesium Mg
Atomic no. 12
Mass number 24



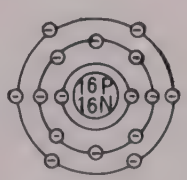
Aluminium Al
Atomic no. 13
Mass number 27



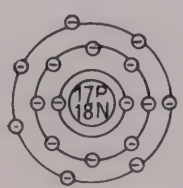
Silicon Si
Atomic no. 14
Mass number 28



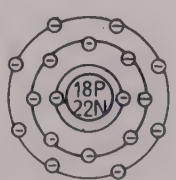
Phosphorus P
Atomic no. 15
Mass number 31



Sulphur S
Atomic no. 16
Mass number 32



Chlorine Cl
Atomic no. 17
Mass number 35



Argon Ar
Atomic no. 18
Mass number 40

Figure 36. The structure of atoms of certain selected isotopes of some elements.

⊕ Protons ● Neutrons ⊖ Electrons

The drawings of the atoms show the structure of one of the isotopes of each of these elements. We have chosen the particular isotope that is most abundant in any specimen of the element found in its natural state. There is not sufficient space to draw all the isotopes even if we knew how many existed.

The most complicated atom that is found naturally in the earth is uranium which has an atomic number of 92, a mass number of 238, and therefore has 92 protons and 146 neutrons in the nucleus. In its neutral state it has also 92 electrons in the various orbits in 7 different shells around the nucleus.

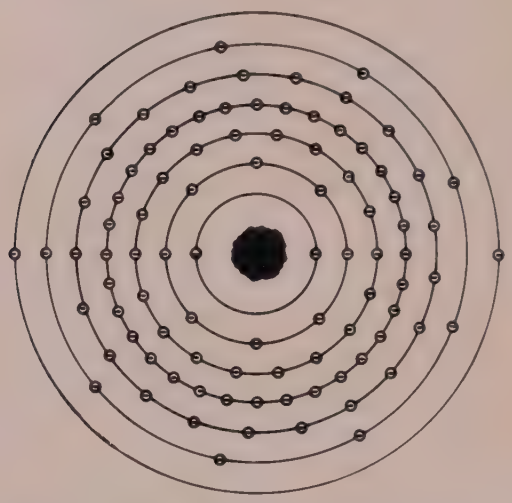


Figure 37. The uranium atom U 238 as it would look if flattened instead of being in three dimensions as it really is.

Elements that are found in their natural state either as recovered from their ores or as formed by chemical processes are now known to be a mixture of many isotopes. Each of these isotopes has a different mass number. The *chemical atomic weights* of elements are determined by their combining masses in chemical reactions involving very large numbers of atoms of various isotopes. If we knew how many atoms of each isotope of an element took part in any reaction we could easily calculate from their mass numbers what the combining mass should be and hence the value known as the chemical atomic weight. For example, we think chlorine is mainly composed of two isotopes of mass numbers 35 and 37. We also think that natural chlorine gas as made industrially or in the laboratory contains about 75 per cent of the chlorine of mass number 35 and 25 per cent of the chlorine of mass number 37. So that the mixture of these two gases of chlorine which normally takes part in a chemical reaction has a chemical atomic weight of 35·5. This value agrees with that found by chemists.

Many elements, however, are not found having measurable

amounts of all the isotopes, some have only very minute amounts of some of the isotopes and large amounts of other isotopes. Magnesium, sulphur, copper, and uranium are some of these elements. As we shall be considering nuclear energy later in this book it is worth while noting here that uranium has two important isotopes: (1) uranium 238, whose mass number is 238, disintegrates to form an isotope of lead; (2) uranium 235, whose mass number is 235, is used as a fuel in nuclear energy reactors. However, for every 145 parts of uranium 238 found in nature there is only 1 part of uranium 235.

Nearly every element, as it occurs in nature, is now known to consist of a mixture of two or more isotopes.

Iron has four isotopes because its nucleus contains 26 protons and either 28, 30, 31, or 32 neutrons, so there is iron 54, iron 56, iron 57, and iron 58. The numbers 54, 56, 57, and 58 indicate the mass number or the total number of protons and neutrons in the nucleus. The element tin as found naturally is a mixture of 10 isotopes, and mercury has 7 isotopes.

The isotopes of hydrogen have played such an important part in the development of the release of energy from uranium nuclei that they have been named *deuterium* and *tritium*, as you will have noticed in the drawings. Deuterium, or as it is sometimes called 'heavy' hydrogen, forms with oxygen 'heavy' water. It was to obtain supplies of this precious liquid, used as we shall learn later for nuclear energy work, that there was so much fighting in Norway in the Second World War.

Some things to do

1 Prepare a short talk to give to your class on the life of one of the following: Franklin, Volta, Röntgen, Mendeleev, Becquerel, the Curies, Moseley, Thomson, Rutherford, Chadwick, and Bohr.

2 Prepare a talk on one of these subjects and illustrate your talk by selecting certain frames from some of the filmstrips mentioned below. The electron, cathode rays, radioactivity, isotopes, and the transmutation of elements.

3 If you can visit a Science Museum like the one in South Kensington, London, try to arrange to spend several hours there in order to see some of the original pieces of apparatus. If you cannot do this try to see some filmstrips and films which show the same apparatus.

4 Demonstrate to yourself the meaning of the half-life of a radioactive element. Take a large sheet of newspaper already creased in halves. Suppose the half-life is 5 seconds. Tear the sheet in half as you count out 5 seconds and throw one half away. Repeat this operation with the remaining half. Continue as long as you can always discarding one half of the remainder every 5 seconds.

Wallcharts

From E.F.V.A.: *Atomic Energy*, Parts 1 and 2, and *Atomic Theory*, Parts 1, 2, 3, and 7.

Filmstrips

From E.F.V.A.: *The Curies and Radium*, No. 555 G 1; and *X-Rays in Use Today*, No. 556 G 1.

Films

From the Rank Film Library: *Science for the Space Age: Electrons at Work*. From E.F.V.A.: *Radioactivity*, No. 555 D 2.

Books

E. RUBIN. *The Curies and Radium*. Chatto & Windus (The Immortals of Science series)

R. McKOWN. *Marie Curie*. A. & C. Black

E. DOORLY. *The Radium Woman*. Heinemann

N. WYMER. *Medical Scientists and Doctors (Series 4)*. O.U.P.

H. BELLIS. *History through Great Lives (Book 4)*. Cassell

J. L. PUTMAN. *Isotopes*. Pelican

A History of Science and Technology. Part 2. Pelican

A. V. HOWARD. *Chambers's Dictionary of Scientists*. Chambers

S. R. RIEDMAN. *Men and Women behind the Atom*. Abelard-Schuman

A. ROMER. *The Restless Atom*. Heinemann

D. W. HUTCHINGS. *Discovering the Atom*. U.L.P.

Oxford Junior Encyclopaedia, Vols. 3, 5, and 8. O.U.P.

Problem C

How does the theory of the structure of an atom 'explain' chemistry?

The structure of the atom has become clear, and all the evidence so far indicates that scientists have succeeded in their investigations. We must be cautious about this, however, because scientists in the years to come may quite well suggest a new theory to explain all that we now assume to be conclusive. We have only to think of the success that Dalton's atomic theory had before Thomson, Rutherford, and Chadwick discovered the electron, the proton, and the neutron. If a new theory is proposed, as good scientists we shall listen and devise experiments to test its validity. If the observations are satisfactory we shall abandon the Rutherford–Bohr atomic theory of the nucleus and the orbiting electrons for the new theory.

Our experiments and our mathematical calculations seem to indicate that matter and energy are so closely connected that an easier and more correct explanation of these two may be possible.

The structure of atoms is the key to our understanding of chemistry. The properties of the elements are directly connected with the structure of their atoms. The way that elements combine to make compounds and the way that some elements refuse to react with other elements will be understood as we proceed further with this problem.

Using our present knowledge we have been able in nearly all cases to explain the reasons for the various chemical reactions that occur not only in the laboratory but also when these are applied to industrial processes.

Question C.1. How are the electrons arranged in an atom?

Rutherford and Bohr suggested that the electrons in the atom spin in orbits in definite shells. Experiments show that there is a definite maximum number of electrons in each shell.

There may be fewer electrons than this number but never more. If the shell is full, and there is an extra electron available, for some reason it has to start another shell farther out from the central nucleus.

If you will now turn back to the drawings on page 35 you will find one electron in the case of hydrogen and two electrons in the case of helium in the smallest shell.

The next element, with atomic number 3, is lithium, which has 3 protons and 3 electrons, and these 3 electrons are arranged with 2 in the smallest shell and 1 in the next sized shell farther from the nucleus.

Study carefully the drawings of the atoms of each one of the other elements whose atomic numbers are 4, 5, 6, 7, 8, 9, and 10. Each additional electron finds a place in the second shell as far as *neon* whose atomic number is 10. This shell is then full and you will notice that the next element sodium, atomic number 11, has to start filling up another shell farther away still from the nucleus. When 8 electrons have gone into this shell another inert gas, *argon* whose atomic number is 18, is formed.

We have not been able to consider all the different atoms, but we observe that the atoms of the *inert* gases never combine chemically with any other elements.

Compare the drawings which show the atoms of three of these inert gases, helium, neon, and argon. Why do you think these particular atoms are inert? You will notice that each one

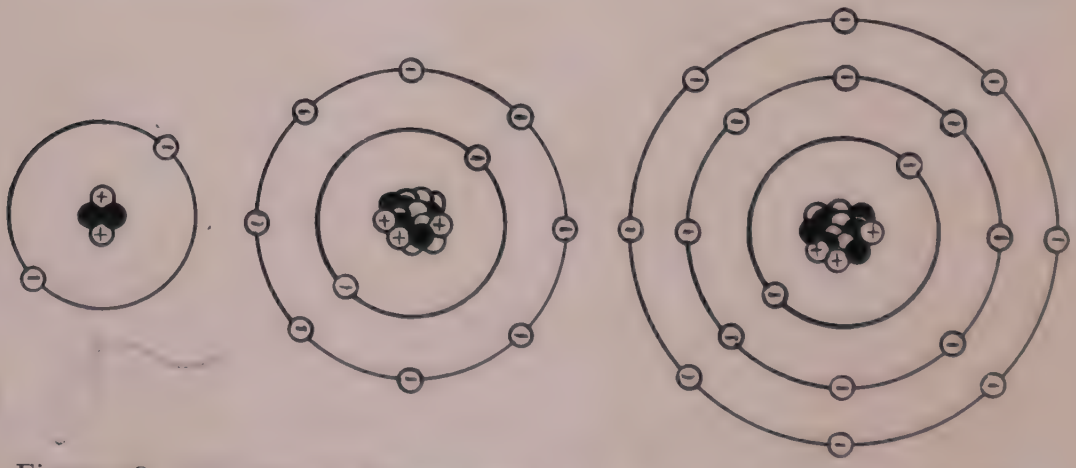


Figure 38. The atoms of three inert gases. Reading from left to right—helium, neon, and argon.

forms a neat tidy sphere with no empty spaces and no spare electrons. It is not difficult to imagine that in these circumstances these atoms have no great attraction for any other atom. In other words these atoms are chemically completely stable, and are thus well named the inert gases. Others are krypton, xenon, and radon but these are relatively rare.

Perhaps you may wonder why, if there is so much empty space in the atom, it behaves as if it were a hard solid sphere. The answer is that the electrons move very rapidly around their orbits at a speed that would take them five times round the earth in a second. If you think of a small spinning electric fan you know that it has a guard to prevent your finger being hurt, as it would be if you were to touch it accidentally anywhere on the spinning blades. If you throw small ping-pong balls at the blades they will bounce off as if the spinning blades formed a solid circular wall. We think it is the same principle with the electrons spinning round on the outside of the atom. The high-speed electrons form a barrier which makes it difficult for anything to penetrate inside.

Question C.2. Why do some elements react with one another?

We discussed in the last question why certain elements are inactive—there are few of these inert gases. Most elements are active—some are more active than others and will take every opportunity of combining to form compounds that are more stable. Some of the most vigorous are fluorine, chlorine, bromine, and iodine. Fluorine will attack glass! Chlorine is a suffocating poisonous gas that easily combines with sodium to form sodium chloride or common salt, one of the most widespread of substances on land or in the sea. Bromine will burn human flesh and the sores formed heal with difficulty. Iodine destroys bacteria and is used for its antiseptic properties. Some of the active solids are sodium, potassium, and to a lesser extent calcium. These solids are found widely over the earth's surface in combination with other elements.

About 60 per cent of the solid crust of the earth is composed of hard, stable, hexagonal crystals. They are known as rock

Figure 39. Crystals of quartz.

crystals (or quartz) and are chemically silicon dioxide, SiO_2. These attractive sparkling crystals are often found in nature coloured with traces of various oxides to form beautiful shades of yellow, rose, brown, grey, green, and black. The amethyst quartz, smoky quartz, and the milky quartz are some of the most treasured specimens. Quartz also forms most of the common sand of the sea-shore.

Why is this crystal so stable and permanent?

Let us consider the structure of the atoms of silicon and oxygen of which quartz or silica is made. They are both active elements and the drawing will help to explain why this is. They have been drawn purposely in positions to illustrate the reason why they are attracted to

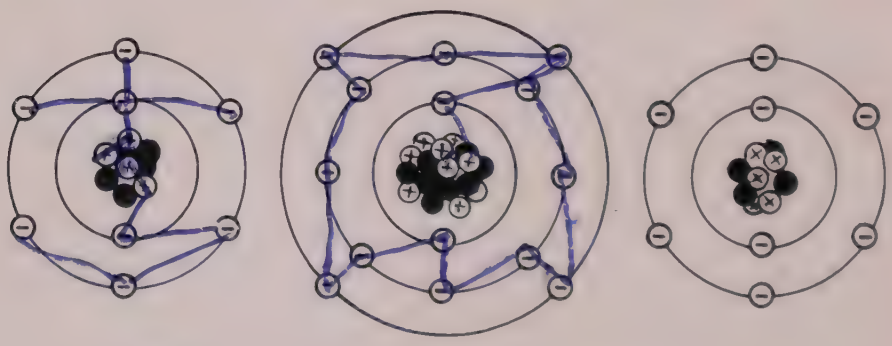


Figure 40. A silicon and two oxygen atoms.

one another. The silicon atom has four electrons in the outermost or third shell. The oxygen has six electrons in its outermost or second shell—which is two electrons short of the number required to fill the shell completely. Each of the three atoms becomes satisfied if the four electrons in the outermost shell of the silicon atom are shared with the two oxygen atoms so that each oxygen atom has an arrangement of electrons

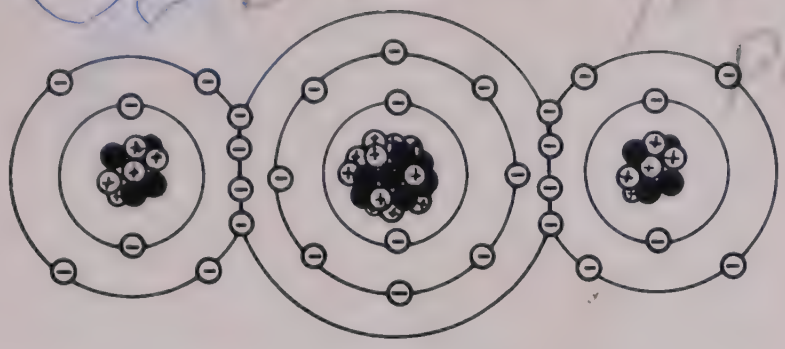


Figure 41. A silicon dioxide molecule.

similar to that in the inert gas neon and the silicon atom has an arrangement of electrons similar to that of argon.

No other electrons are involved in this change and the nucleus of each atom remains unaltered. The compound silicon dioxide has no extra electrons in the outermost shells and there are no spaces to be filled, so it is absolutely stable.

Examine carefully the structures of the sodium and the chlorine atoms and you will understand how it is that a similar combination of sodium and chlorine (sodium chloride) is so powerful and stable that it is found everywhere. In island countries like Britain it is present in the air one breathes and it is hardly possible to light the flame of a Bunsen burner without noticing the yellow colouring due to the sodium of this salt in the air.

Question C.3. How is electrolysis explained?

Let us consider what has happened to the sodium and chlorine atoms which you examined at the end of the last question. They combined together to produce sodium chloride and in doing so the sodium atom lost one electron to the chlorine atom. An electron carries one unit of negative electric charge. To lose a negative charge is the same as gaining a positive charge. Thus the sodium has become positively charged by the amount of one unit. It is now no longer called a sodium atom but a *sodium ion*.

The chlorine atom gains a negatively charged electron. It therefore becomes negatively charged by the amount of one unit. It is then a *chloride ion*, and its outer shell is full of electrons.

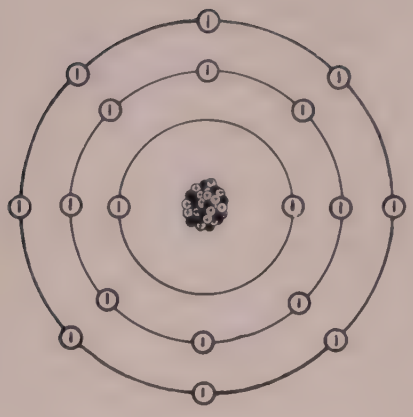


Figure 42. A chloride ion.

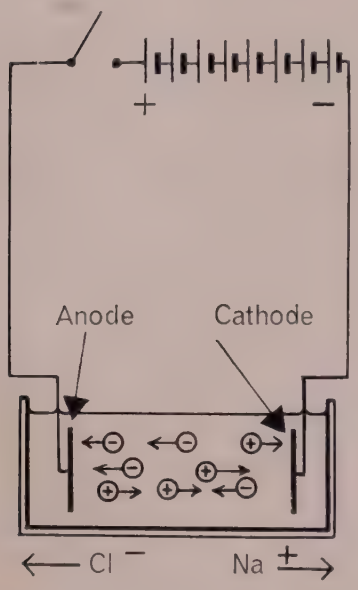


Figure 43. The electrolysis of sodium chloride.

One of the reasons why sodium chloride is a very stable compound is that the positive sodium ion and the negative chloride ion attract one another. In its solid state it is a crystal and if you examine many crystals of sodium chloride you will find they are all alike, having the same angles and shapes for their faces (see Figure 12). If you can 'grow' a large crystal you will find that this is the same shape as the smaller crystals. If you melt a quantity of sodium chloride and then pass an electric current through the liquid, the positive sodium ions start to move in one direction towards the cathode and the negative chloride ions move in the other direction towards the anode. This process is known as electrolysis.

What happens to the positive sodium ions when they hit the negatively charged cathode? An electron (−ve charge) is attracted to each sodium ion (+ve charge) to produce a neutral sodium atom. When a large number of these ions have changed to the metallic sodium atoms these can be removed from the cathode. Hence sodium may be recovered from molten sodium chloride by electrolysis. This is, in fact, how pure sodium metal is obtained industrially.

The chloride ions arrive at the anode and there give up their negative charges or electrons. These electrons travel along the cable from the anode plate to the battery to complete the electrical circuit. The neutral chlorine atoms collect together and rise as bubbles in the molten liquid.

An electric current is, as we know, a movement of electrons

along and round a closed electrical circuit. The current in the external circuit (not in the battery) flows from the positive plate of the battery to the negative, and the electrons from the negative plate to the positive plate.

Summary of our knowledge of the structure of an atom

The atom consists of a *nucleus* and around it *electrons* spin in orbits in fixed shells.

The interior of an atom is mostly empty space and the electrons are at relatively great distances from the nucleus.

The nucleus consists of *protons* and *neutrons* and is where the mass is concentrated.

A proton has 1 unit of positive charge and 1 unit of mass.

A neutron has no charge and 1 unit of mass.

An electron has 1 unit of negative charge and negligible mass.

The maximum number of electrons that can be contained in each shell around the nucleus is fixed and a new shell has to be started if this number is exceeded.

If the *atom is electrically neutral* the number of protons equals the number of electrons.

The atomic number of an atom is the number of protons contained in its nucleus.

The mass number of an atom is the number of protons and neutrons added together.

An element is a simple substance whose atoms have all the same atomic numbers.

The isotopes of an element are different forms of the same element, all chemically alike and having the same atomic numbers but with different mass numbers.

A compound consists of two or more elements combined chemically in definite proportions.

Chemical reactions between simple elements involve only the electrons in the outermost shells of the atoms concerned.

Some things to do

Without reference to the previous pages answer the following questions. There is only one correct answer to each question and this can be indicated by its letter. Only when you have completed all the questions may you look on the last page to find the correct answers.

1 Which particle has the least mass? *a.* a proton, *b.* a neutron, or *c.* an electron.

2 What electric charge does a proton possess? *a.* positive, *b.* none, or *c.* negative.

3 What electric charge does a neutron possess? *a.* positive, *b.* none, or *c.* negative.

4 What electric charge does an electron possess? *a.* positive, *b.* none, or *c.* negative.

5 Which particle is farthest from the centre of an atom? *a.* a proton, *b.* a neutron, or *c.* an electron.

6 Which particle was discovered first? *a.* a proton, *b.* a neutron, or *c.* an electron.

7 Who was the first person to discover and name the proton? *a.* Boyle, *b.* Dalton, *c.* Thomson, *d.* Rutherford, *e.* Chadwick, *f.* Einstein, or *g.* Bohr.

8 Who was the first person to discover and name the neutron? *a.* Aristotle, *b.* Avogadro, *c.* Volta, *d.* Moseley, *e.* Chadwick, *f.* Cavendish, or *g.* the Curies.

9 Who was the first person to discover and name the electron? *a.* Archimedes, *b.* Galileo, *c.* Boyle, *d.* Dalton, *e.* Franklin, *f.* Thomson, or *g.* Becquerel.

10 Isotopes are elements which have the same *a.* mass number, *b.* atomic number, or *c.* number of electrons?

11 If you burn some magnesium ribbon in air, what would the magnesium and the oxygen form? *a.* an isotope of magnesium, *b.* an isotope of oxygen, *c.* a compound, *d.* a mixture, or *e.* another element.

12 When β particles are driven hard against a solid metal

block do they form *a.* more β particles, *b.* α particles, *c.* X-rays, or *d.* gamma rays?

13 Who was the first person to see, with the aid of instruments, the nucleus of an atom? *a.* Leeuwenhoek, *b.* Dalton, *c.* Thomson, *d.* Rutherford, *e.* Einstein, or *f.* nobody at all.

14 How many electrons are there in the stable neutral atom of neon? *a.* 2, *b.* 8, *c.* 10, *d.* 18, or *e.* 20.

15 Has the nucleus of the neutral deuterium atom *a.* 1 proton, *b.* 1 neutron, *c.* 1 proton and 1 neutron, *d.* 2 protons and 1 neutron, *e.* 1 proton and 2 neutrons, or *f.* 2 protons and 2 neutrons?

16 The atomic number of an uncharged atom of uranium is 92 and its mass number is 238. How many electrons are spinning in orbits around its nucleus? *a.* 54, *b.* 92, *c.* 146, *d.* 238, *e.* 300, or *f.* 330.

Filmstrips

From Educational Productions Ltd: *Chemical Change*, No. 5207.
From E.F.V.A.: *The Structure of the Atom*, No. 557 H 26.
From Common Ground: *The Structure of Matter*, No. CGB 773.

Films

From Rank Film Library, of 1 Aintree Road, Perivale,. Greenford, Middlesex: *Science for the Space Age*, (1) *Evidence for Molecules and Atoms;* (2) *The World of Molecules.*
From B.B.C. Television Enterprises, Lime Grove, London, W.12: *The Nature of Things—Atoms and Molecules.*

Books

L. DE VRIES. *The Book of the Atom*, translated by E. G. Breeze (John Murray). This is a popular, exciting, and even romantic presentation of the atom and nuclear energy.

Two other more serious books are:

C. HATCHER. *The Atom.* Macmillan

E. W. TITTERTON. *Facing the Atomic Future*, Part 1. Macmillan

Problem D

How can the energy of an atom be released?

In the solving of this problem we shall share with the scientists some of the excitements that spurred them on to the great achievement of this age, if not the greatest in the whole of human history. It is a fascinating story of men and women of many nations all working and freely sharing their discoveries with one another in an attempt to release the stupendous energy stored in the nucleus of an atom. These men and women were citizens of nations that, before this story was complete, were engaged in the bitterest and most devastating war man has ever known.

Although we cannot tell the whole of their stories they include those of men who escaped to continue working in the lands of their choice; of men who fought fierce battles to destroy the supplies and the factories of that precious liquid heavy water of which only a little was known to exist; of those who escaped taking the whole of their nation's supply of heavy water with them. They relate how suddenly the strictest security measures were taken to keep the secrets of those scientists; and also of the misgivings of some of these scientists when they realised how disastrous their nuclear bomb was to be. There are numerous tales to tell also of the intrigues, arguments, deceptions, fears, and hopes of the nations at war.

It is alien to the nature of scientists to keep their discoveries and knowledge secret. All scientists of all nations have always shared freely their successes and failures for the benefit of all men. But war involving everyone created another way of life in which the discoveries of scientists are of vital importance.

Eventually the uncontrolled release of the energy of the nucleus of the atom was achieved by the scientists of one side in that conflict, and shortly afterwards in 1945 this energy, released in the form of a bomb, was used by them to bring the war to an end.

To 'tame' or to release this energy slowly and under con-

trol needed several more years of careful research work. It was not until 1951 at Idaho Falls in U.S.A. that the first electric lamp was lighted with electricity derived from nuclear energy.

The story of the winning of nuclear energy by scientists is an example of how rapid progress and achievements necessary in war can be used to give great advantages in peace. Some think that the limit of man's destructive power has now been reached. Using this knowledge he has gained of the slow release of nuclear energy he is in a position to devote himself to constructive efforts, and the energy derived from the nucleus of the atom will enable him to do this with greater speed and comfort. He has now the means to devise a much higher standard of living if he will use it.

The wonderful scientific success of the release of energy is a splendid example of how the scientist works and the methods he uses. It tells of his search into the smallest things and of his use of the largest machines to assist his work. It tells of experiments carefully planned and brilliantly carried out. It tells of accidental discoveries and clever hunches. In fact, the whole of it is in the true spirit of science.

Question D.1. What energy is available in an atom?

Many scientists were puzzled by an apparent contradiction of the principles they had assumed about bodies carrying electrical charges. In the nucleus of an atom a number of protons and neutrons are tightly packed together. Similarly charged bodies we know repel one another. Why then should the protons remain together if electrical forces are pushing them apart? At the same time it is known that gravitational forces pull two bodies together, for example, when you release a pencil. The pencil and the

Figure 44. The nucleus of an atom.

earth attract each other and we observe that the pencil 'drops' towards the centre of the earth.

There are obviously two forces in the nucleus of an atom acting in opposite ways—one pushing the protons apart and the other pulling the neutrons and the protons together. Which of these forces is the greater—the electrical or the gravitational? It was found by calculation that the electrical forces are much greater than the gravitational forces. Then scientists realised that in order to keep the nucleus together other forces must be present. What these forces were was the puzzling problem of the day.

The solution was given in 1905 by a young German when he was working as a clerk in the Swiss patents office in Berne. His name was Albert Einstein and he was to become one of the most brilliant mathematicians and scientists of the century. He said that matter and energy were different forms of the same thing. No wonder his theory at first seemed unbelievable! He showed how matter could be converted into a certain quantity of energy, and he supposed that these other forces could arise from such an interchange. This was the explanation of the binding together of the protons and neutrons in the nucleus of an atom.

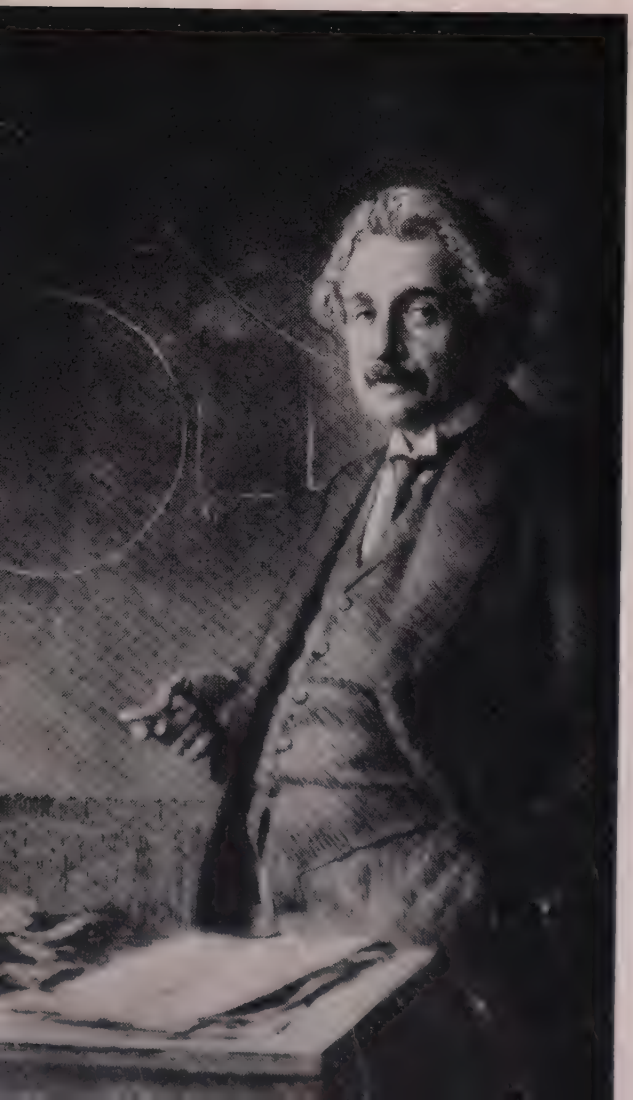


Figure 45. Albert Einstein (1879–1956) whose brilliant research in physics provided the theoretical foundations for the development of nuclear energy studies.

We have always thought that matter cannot be created or destroyed and that energy cannot be created or destroyed, but Einstein has shown exactly how one may be changed into the other. Radium has always been converting some of its matter into energy by the process of

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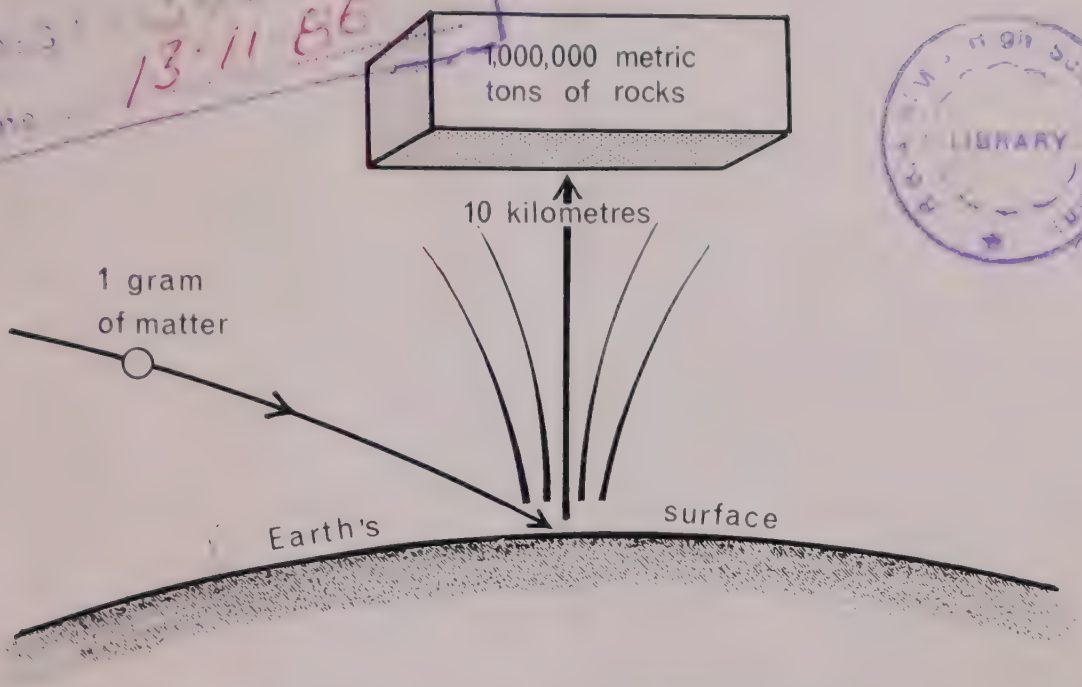

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Figure 46. The transformation of 1 gram of matter into sufficient energy to raise 1 million metric tons 10 kilometres high.

radioactivity. Einstein's famous equation, $E = m \times c^2$, shows how to calculate the tremendous quantity of energy produced by the conversion of a minute amount of matter. In the equation E represents the energy liberated in ergs, m represents the mass of the material consumed in grams, and c is the large number 3×10^{10} centimetres per second. In the equation c^2 therefore involves the number 900,000,000,000,000,000,000! This number is so large we cannot imagine it at all, but we have to use it when we calculate that 1 gram of matter converted into energy will generate 200 millions of units of electrical energy. This quantity of electricity is sufficient to illuminate an average room for 2,000 years. It would require several thousand tons of coal to produce the same quantity of electricity. This fantastic source of energy as we shall learn later in this book is now harnessed and utilised.

If a piece of coal is burnt the forces holding the atoms together are rearranged and energy released. This chemical energy from the coal appears in the form of heat energy which can then be used for cooking, warming homes, and generating electricity. But if the much stronger forces holding together the nucleus of an atom are disturbed, energy many million

times greater than the chemical energy is released. This is 'nuclear' energy and is usually also given off in the form of heat.

Such enormous supplies of energy as are concealed in the nucleus of an atom led scientists to try to find a way of releasing them. Various ways were thought of but it became

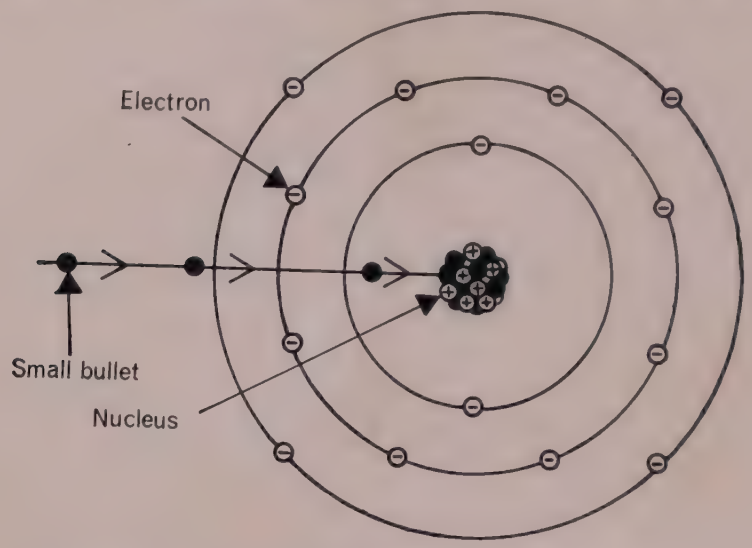

Figure 47. Shooting at the nucleus of an atom.

clear that the one sure way was to break up its structure by shooting some kind of small bullet at its nucleus and hitting it.

Question D.2. How can an atom be smashed?

The idea of shooting some kind of bullet into the nucleus of an atom proved finally to be the right one. Many difficulties were encountered in choosing the right bullet and the right nucleus for the operation.

There were many particles known, all of which could be used: proton, neutron, electron, deuteron (the nucleus of the heavy hydrogen atom), and an alpha particle.

Three ways of speeding up or accelerating and projecting these particles were constructed—one was the generator of Cockcroft and Walton, another was Van der Graaff's generator, and the third was the cyclotron designed by Lawrence in 1929. Two of these accelerators produced electrical fields amounting to millions of volts per metre.

Rutherford was the first man to smash the nucleus of an atom

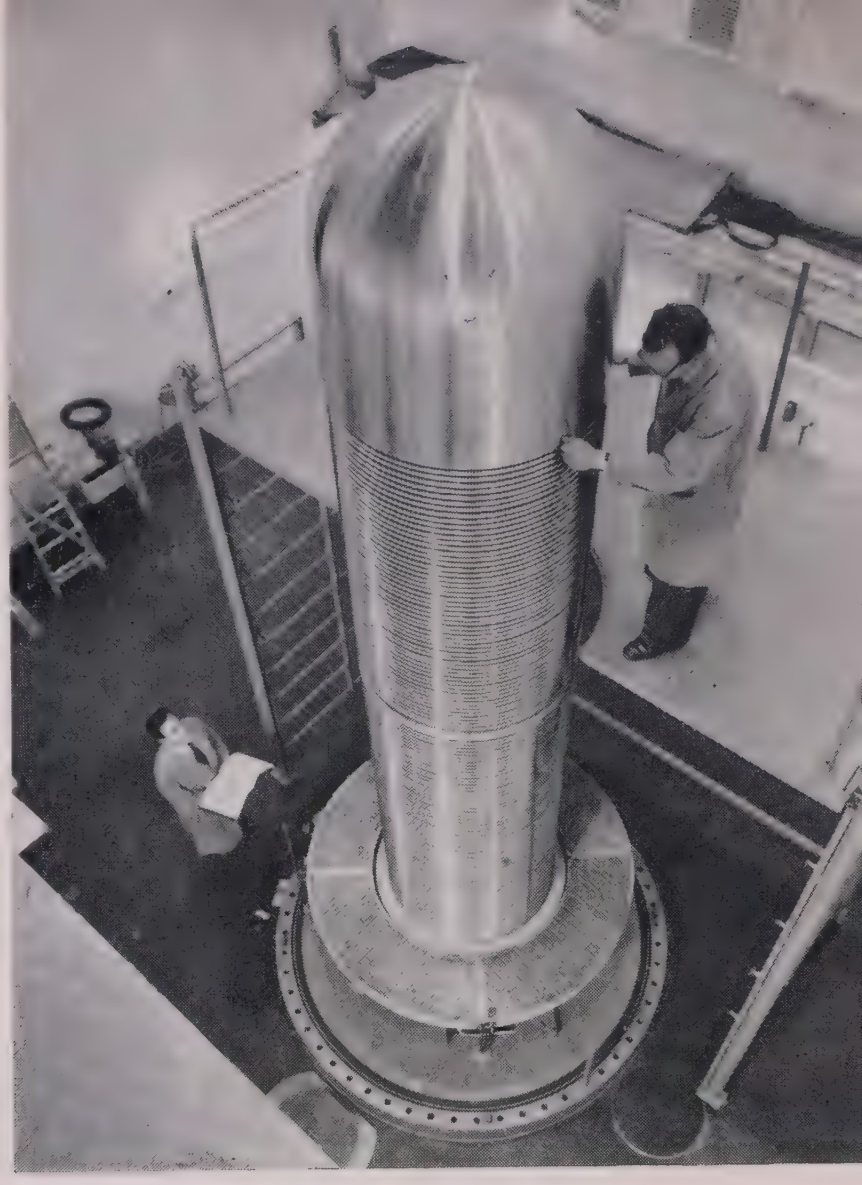

Figure 48. Van der Graaff's generator of millions of volts used for accelerating particles to smash the nucleus of an atom. The charges are collected on the dome at the top and the value of the potential there can be varied. The dome is insulated from the base by a large number of resistors seen as ribs along the vertical column.

when he bombarded nitrogen with alpha particles from radium and obtained the proton. This was described on page 30.

In 1932 protons that had been speeded up by one of the accelerators described, were shot at the element lithium. The result was that another surprising disruption occurred when the nucleus of the lithium atom formed two helium nuclei and released a large amount of energy. The energy had come from the conversion of the mass lost during the collision. The difference between the combined masses of the lithium nucleus and a proton and the masses of the two helium nuclei produced is small but suffices to account for the large amount of energy liberated.

Using one or other of the particle accelerators and one of the many possible particles scientists bombarded several different elements with increasing success.

The neutron is a most effective particle to use for certain

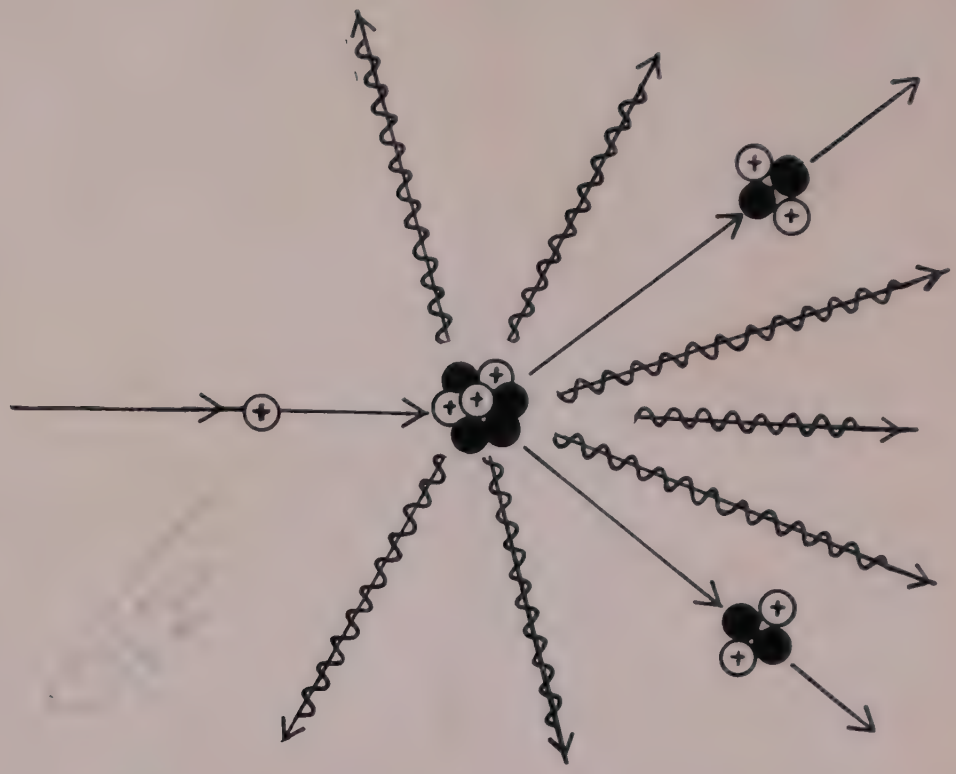

Figure 49. The bombardment of a lithium nucleus by a fast-moving proton producing two helium nuclei (alpha particles) and large quantities of energy.

collisions because it has no electrical charge and is not therefore repelled by the positive electrical charge on the nucleus of the atom it attempts to hit. The only disadvantage is that since neutrons carry no charges the great particle accelerators cannot be used to speed them on their journey into the nucleus. Nevertheless other indirect ways of speeding them were found and atom smashing became one of the operations much used by scientists for increasing their knowledge of the release of energy from the nucleus of an atom.

Question D.3. What is nuclear fission?

As scientists continued to study the bombardment of the nuclei of atoms their attention was directed to some of the heavier elements. We learned earlier that many of these nuclei are unstable in their natural state, in other words they are radioactive.

It was an Italian scientist, Enrico Fermi, who in 1934

bombarded uranium with neutrons and found that some interesting products were formed which emitted electrons.

Four years later the two German scientists Hahn and Strassman found that the substances which were giving off electrons were barium and krypton whose atomic numbers were 56 and 36. The neutrons had therefore split the nuclei of uranium whose atomic number is 92 into two pieces having atomic numbers 56 and 36. This process is known as *nuclear fission.*

Other ways of splitting the uranium nucleus were soon found. In each case vast quantities of energy were released that always agreed with Einstein's equation, $E = m \times c^2$.

Another product of nuclear fission was the shooting out of more neutrons—sometimes two or three for every neutron absorbed during the bombardment. This meant that these

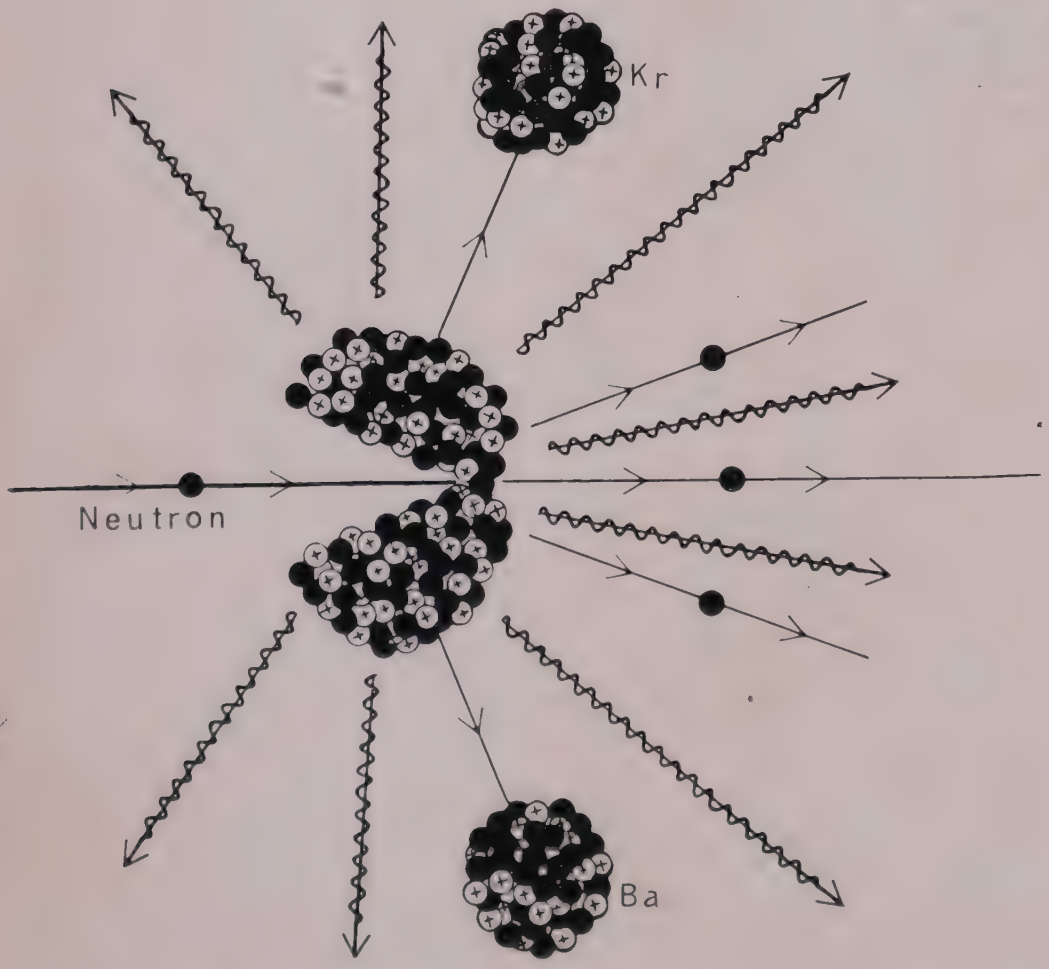

Figure 30. The fission of a uranium nucleus by a neutron. The products of fission Krypton (Kr) and Barium (Ba) and three new neutrons are shown as well as vast quantities of energy.

newly formed neutrons were capable of producing more nuclear fission if other uranium nuclei were within their range. The process is a continuous one and grows by what is termed a *chain reaction.*

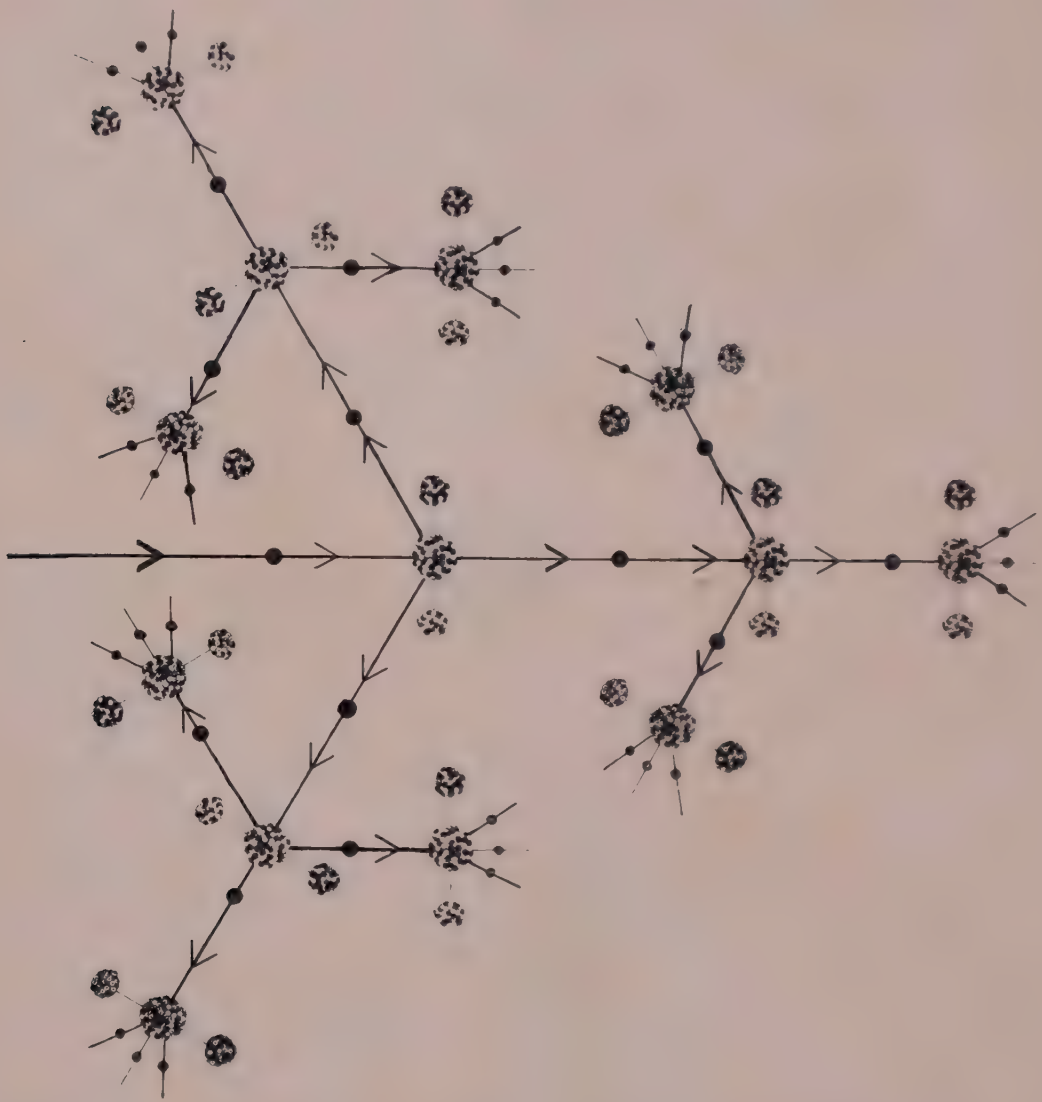

Figure 51. A chain reaction in uranium. For the sake of clarity the products of fission (Kr and Ba) have not been labelled.

It was the unstable isotope of uranium, known as U 235, which was required to produce nuclear fission. In natural uranium (as stated on page 37) only a small quantity of U 235 is found with a large quantity of U 238. It needed some clever thinking to find a method of separating these two isotopes in order to obtain a sufficient quantity of U 235 for a chain reaction to take place. If it is once started, nuclear fission of U 235

will continue as a chain reaction, provided that the newly formed neutrons find more U 235 nuclei. This means that the piece of U 235 must be big enough, otherwise the neutrons escape and nothing further happens.

Two pieces of uranium 235, each just less than the size needed for a chain reaction, are mounted in a case apart from each other to form a *nuclear bomb*. As soon as these two pieces are brought together a total piece big enough to maintain a chain reaction is created. The neutron bombardment then grows so rapidly that a fierce and uncontrolled explosion takes place.

Some people speak of an atomic bomb but it is the nucleus that divides, not the atom itself, so the words we should use are 'nuclear bomb'.

The first nuclear bomb exploded was a trial one in the deserts of New Mexico during July 1945. A month later the political and military leaders of the United States and her allies decided to use this terrifying and devastating bomb against their enemies in an effort to close the Second World War that had already dragged on far too long and wounded and killed too many millions of men all round the world.

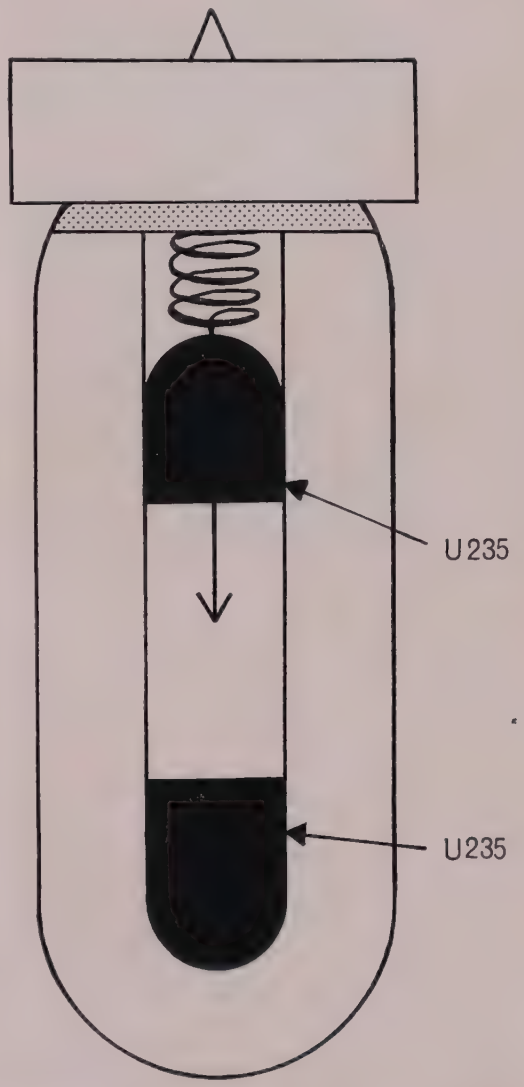

Figure 52. A possible design for a nuclear bomb. The two pieces of U 235 are thrown together to make the bomb explode.

The nuclear bombs dropped on Hiroshima and Nagasaki in Japan succeeded in ending the war, but it left in the minds of those who survived a fear of any future war so great that nobody now thinks a

Figure 53. A nuclear bomb explosion.

war with nuclear bombs can do anything but destroy all that men have striven for since they walked this earth.

May the leaders of our nations great and small, friend and foe, learn to settle their differences by peaceful negotiations.

Question D.4. How can the energy of nuclear fission be released slowly?

A new age dawned for mankind when the nuclear bomb exploded in 1945. It can be called the nuclear age during which man is sure to develop unlimited energy to be used, if he chooses, for his enrichment and comfort. He should be able to satisfy his quest for more and more energy as long as he exists on this planet. This is the greatest challenge of all to man's genius and his sanity.

In the last question we discussed how we can only obtain energy from the nucleus of uranium 235 if we have a mass of a certain *critical size*. Natural uranium which only contains 1 part of U 235 in 145 parts of U 238 is not rich enough in U 235 for fission to be maintained. The reason for this is that the neutrons, produced by the fission of uranium 235 in the presence of uranium 238, escape or are absorbed by the uranium 238 unless they are purposely slowed down. If the neutrons are slowed down by some means then they will bounce off the uranium 238 and will continue to do this until they eventually find another uranium 235 nucleus. When this happens another fission will take place but a chain reaction like that described in the last question will be prevented. Carbon in the form of graphite, heavy water, and even ordinary water

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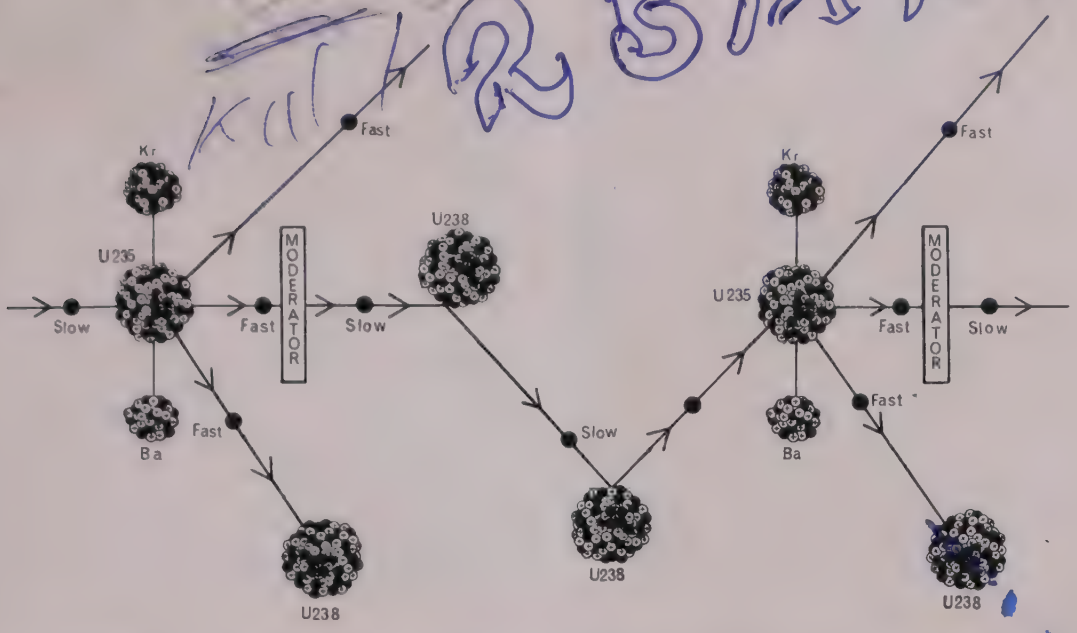


Figure 54. The use of a moderator for slowing the fast neutrons produced in nuclear fission. Some fast neutrons escape or are absorbed by U 238. Slow neutrons bounce off U 238 but produce fission when they hit U 235.

can be used to slow down the neutrons. These substances are known as *moderators*. A slow neutron travels about 4,000 m.p.h.!

The number of neutrons left from each fission to produce a new fission can be controlled by inserting in the path of the neutrons a material, such as boron or cadmium, which easily absorbs neutrons.

If controlled in one of these ways nuclear fission can take place so that out of every three neutrons produced by each fission two escape or are absorbed and only the third neutron goes on to cause another fission.

A simplified drawing is shown of a nuclear reactor using as the fuel ordinary uranium, which is a mixture of U 238 and U 235, and as the moderator pure graphite blocks.

In this reactor control rods of boron mixed with steel are so arranged that they can be raised or lowered between the rods of fuel.

The whole reactor is surrounded by a concrete shield to prevent the escape of dangerous radiation.

Carbon dioxide is pumped rapidly through the reactor to carry away the heat generated by the fission of the uranium nuclei of the fuel. The hot carbon dioxide gas passes through

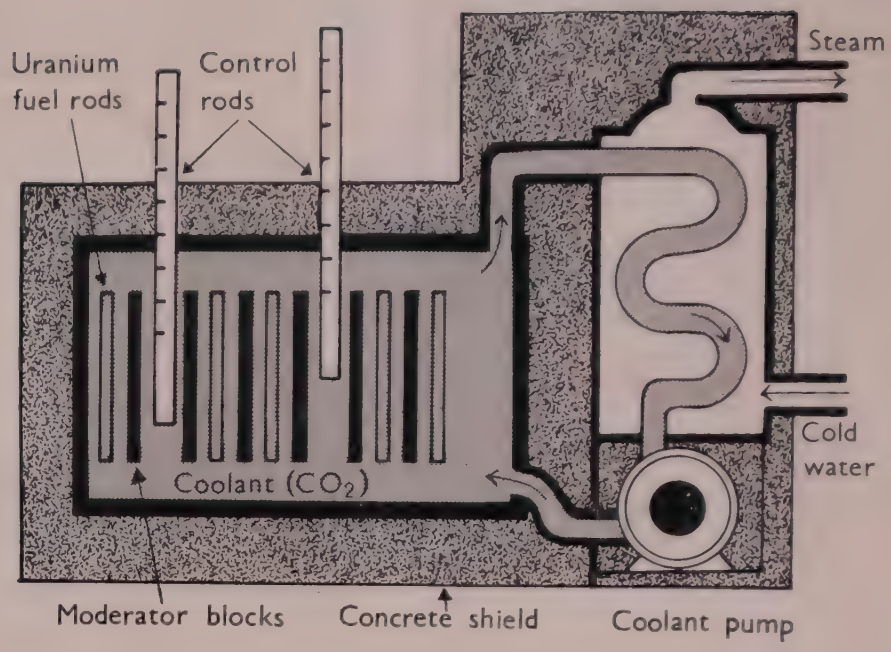


Figure 55. A nuclear reactor with heat exchanger.

a heat exchanger where it gives up its heat to water turning this into steam. The steam then drives the turbines and the alternating current generators of electricity.

The nuclear reaction is started by raising the control rods so that they do not absorb many neutrons. A single neutron is capable of starting fission and there are always a few

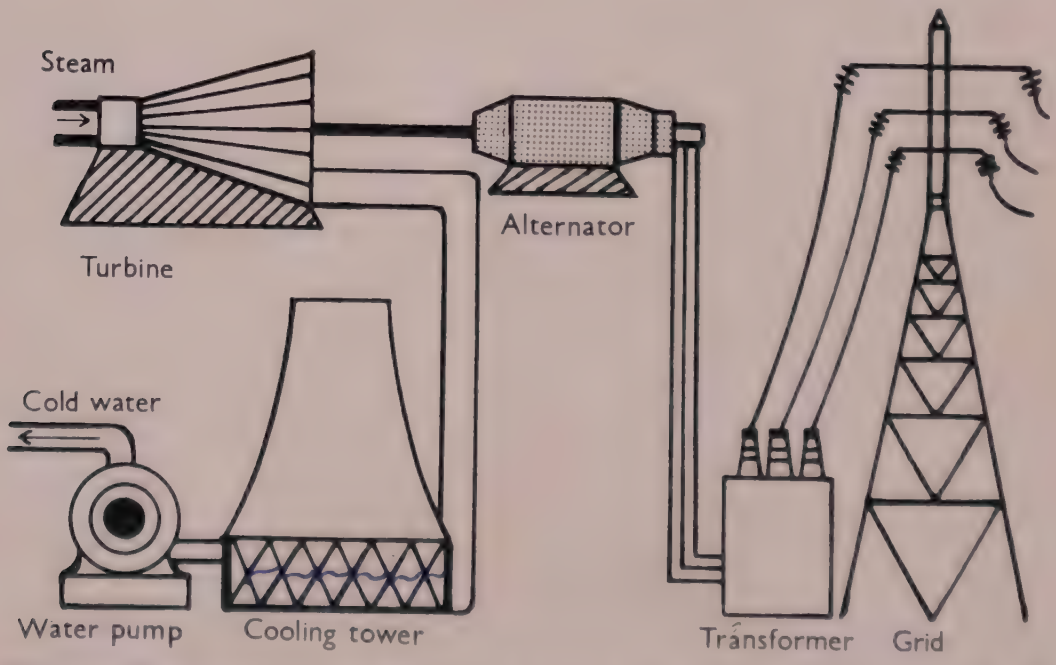


Figure 56. An electricity generating station using the steam produced in the heat exchanger of a nuclear reactor.

Figure 57. Calder Hall, Cumberland, the first large-scale nuclear power station in the world to produce electricity on a commercial scale. There are really two power stations each having a turbine hall placed between two reactors. Two cooling towers are needed to condense the exhaust steam from each set of turbines. An electrical step-up transformer sub-station can just be seen—it connects the electrical power output of the station to the National Grid distribution system.

neutrons present because some of the uranium nuclei disintegrate naturally. Once started the reaction is controlled by moving the control rods in and out.

The world's first commercial station built to convert the energy of nuclear fission into electrical energy was opened at Calder Hall in England in 1956 by Her Majesty the Queen who said: 'Today we are present at the making of history. Atomic scientists, by a series of brilliant discoveries, have brought us to the threshold of a new age. It may well prove to have been among the greatest of our contributions to human welfare that we led the way in demonstrating the peaceful uses of this new source of power.'

You will notice how the reactor buildings at Calder Hall are separated from the other buildings to prevent any harm being done by an accidental leakage of radiations or radioactive waste products.

Advanced gas-cooled reactors are now working at higher temperatures and with higher efficiencies than those of Calder Hall and producing even greater supplies of energy.

Question D.5. What is nuclear fusion?

So far we have been considering the energy released by the splitting of large and complicated heavy nuclei. At first we did not know how to control this release of energy but eventually the problem was solved. We shall now consider another way of releasing energy from the nuclei of atoms.

This other way is called *nuclear fusion* and means the joining together of the nuclei of simple light atoms. There are several ways by which this can be done. The simplest is to join two nuclei of an isotope of hydrogen called deuterium or heavy hydrogen to form a light helium nucleus with the release of a neutron and great quantities of energy.

The nucleus of heavy hydrogen contains one proton and one neutron and when two such nuclei hit each other at very high speeds they fuse together to form a light helium nucleus of two protons and one neutron. Heavy hydrogen exists as 1 part in about 6,000 parts of ordinary hydrogen obtained from water.

We think this kind of nuclear fusion is taking place in the sun and in most of the stars, and that is why the sun is so hot and gives out great heat by radiation. When the sky is clear and the heat radiation can reach us directly it can burn us as we expose ourselves to it even though the sun is 93 million miles away. Until recent years all the energy we have used has been derived from the radiant energy of the sun collected here on earth and stored in some form or other.

It is difficult to make these two heavy hydrogen nuclei travel fast enough so that they fuse together when they collide. One way is to raise them to very high temperatures, of millions of degrees centigrade, far hotter than the temperature of the surface of the sun.

These high temperatures can be obtained by exploding a nuclear fission bomb close to the heavy hydrogen atoms. This procedure created the *hydrogen bomb* and its only use so far is for destruction. The energy released is as much as 1,000 times greater than that of the fission bomb. It is so powerful that with a terrific flash it completely destroyed an island in the Pacific Ocean where the first experimental one was exploded.

It now appears that we are approaching the time when we shall know how to 'tame' the enormous quantity of energy available by the fusion of light nuclei. Scientists have been experimenting with a type of reactor in which temperatures of millions of degrees centigrade have been reached by passing a strong electric current for a fraction of a second through a loop of heavy hydrogen gas surrounded by a strong magnetic field. This experiment has not yet caused fusion to occur. There are still practical difficulties to be solved before the gases can be held long enough at temperatures high enough for the success of this type of nuclear fusion.

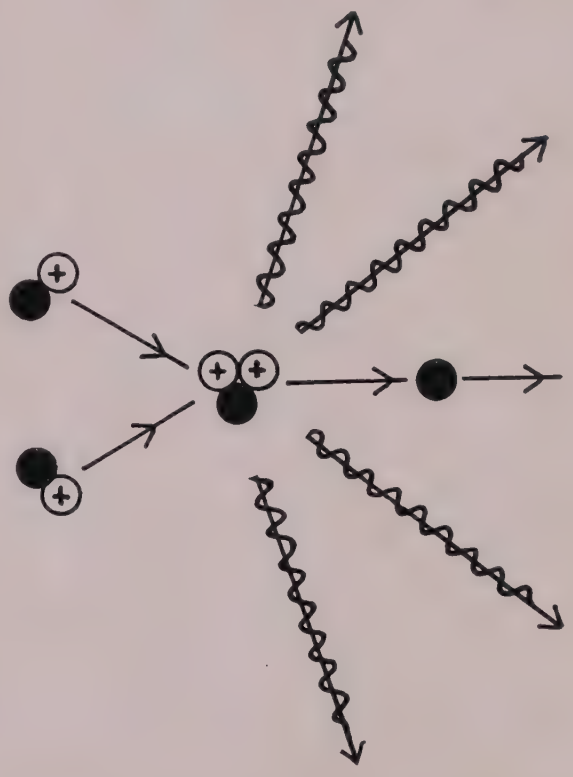


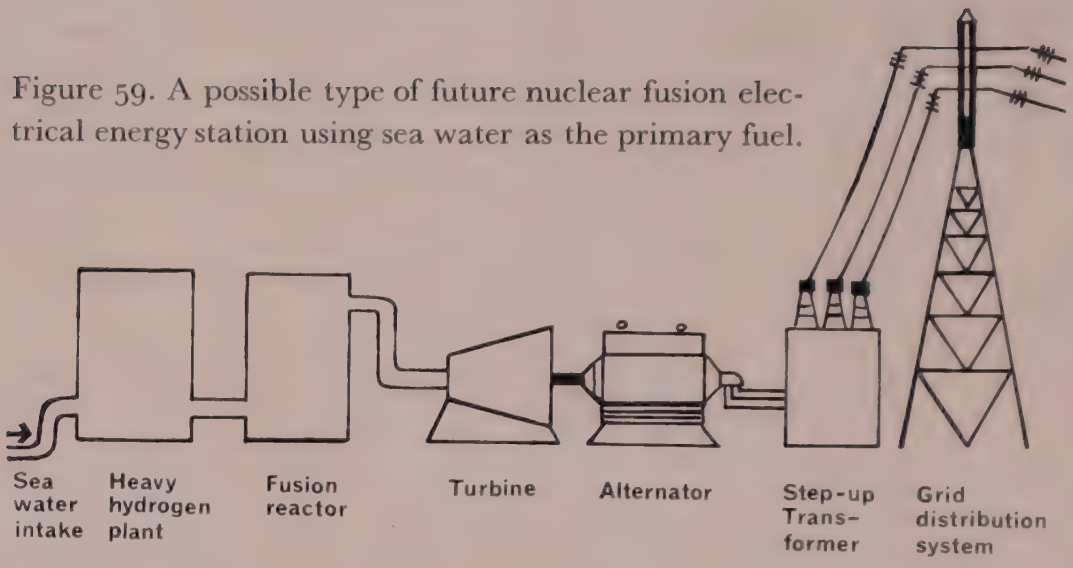
Figure 58. One type of nuclear fusion of two heavy hydrogen nuclei to form one light helium nucleus, a neutron, and an enormous quantity of energy.

Once scientists succeed in these experiments and gain control of nuclear fusion, and then learn to operate it in complete safety, they will have made one of the greatest discoveries of all time, for it will give mankind a vast source of cheap energy.

Why is so much research costing an enormous expenditure in time, energy, and money being given to finding out how to 'tame' nuclear fusion? The reason is that heavy hydrogen is the fuel it burns and this can be obtained cheaply from sea water. The process of separation of heavy hydrogen from sea water is not complicated, and sea water is plentiful.

There is obviously a lot to do before all these problems are solved and no one can say how long this will take. It may be many years before the generation of electrical energy from nuclear fusion becomes a practical proposition. What is certain

Figure 59. A possible type of future nuclear fusion electrical energy station using sea water as the primary fuel.



is that it will require some clear thinking, great patience, and clever experimental work.

Some things to do

1 Examine the wallcharts, filmstrips, and loop films listed below and then prepare to give to your class an illustrated talk on one of the following subjects. If it is possible, illustrate your talk not only by films and loops but also by constructing models with card, sticky tapes, string, paste, and colours.

'The relationship between matter and energy.'
'How nuclear fission can give us energy.'
'How nuclear fission can be controlled.'
'What is meant by a chain reaction.'
'What the hopes are for obtaining energy from nuclear fusion in the future.'
'The destructive power of the nuclear bomb.'
'The working of a Van der Graaff generator.'
'The life and contributions of Albert Einstein.'
'The search for uranium.'

2 Construct one of these models and then put it on display in your science room.

A nuclear bomb. A nuclear reactor. An electricity generating station. A nuclear energy generating station, such as Calder Hall. A Van der Graaff generator. A cyclotron (there is a simple model in the Science Museum, London).

3 It may be possible for someone to build a real Van der Graaff generator; or perhaps someone may be able to borrow one so that you can learn what high voltages can do. These machines can give you a sharp shock so it is advisable to use them only when your teacher is with you.

4 Demonstrate a chain reaction in this way. Take a large sheet of wire gauze and on the gauze lay out matches to represent a chain reaction. Use paper matches and cut off and throw away about two-thirds of the tail of the matches. Make sure you place the head of the matches before the tail in the direction in which the reaction is to proceed. Ignite the head of the first match!

Wallcharts

From E.F.V.A.: *Power Production Posters*; *Nuclear Power Drawings*; *Atomic Power*; *Atomic Energy*, Parts 3, 4, and 5; *Atomic Theory*, Parts 4, 5, and 6.

From Educational Productions Ltd: *Nuclear Fission*, No. C644/3; *Nuclear Fusion*, No. C644/4; *Atomic Power*, No. C644/5; *Uranium*, No. C551.

Filmstrips

From Educational Productions Ltd: *Atomic Energy*, No. 5077.

Loop Films for a Technicolor 800-E Projector.

From E.F.V.A.: *Chain Reaction*, No. 557 R 20; *Critical Size*, No. 557 R 21; *Controlled Chain Reaction*, No. 557 R 22.

Books

E. LARSEN. *Atomic Energy*. Harrap

E. LARSEN. *The Atom*. Weidenfeld & Nicolson

E. LARSEN. *Atoms and Atomic Energy*. Weidenfeld & Nicolson

T. E. ALLIBONE. *The Release and Use of Atomic Energy*. Chapman & Hall. (Royal Institution Christmas Lectures)

K. E. B. JAY. *Calder Hall*. Methuen

D. J. HUGHES. *The Neutron Story*. Heinemann (Advanced)

Lead in Atomic Energy. The Lead Development Association, 18 Adam Street, London W.C.2

Problem E

What are radioactive isotopes?

Some of the isotopes found naturally are radioactive. This means that they explode, or disintegrate, emit an alpha particle, a beta particle, or gamma radiation and become other kinds of atoms. We have discussed earlier in this book the cases of radium and uranium. These are not the only examples of radioactive isotopes or radioisotopes.

It is possible to make radioisotopes from the stable isotopes

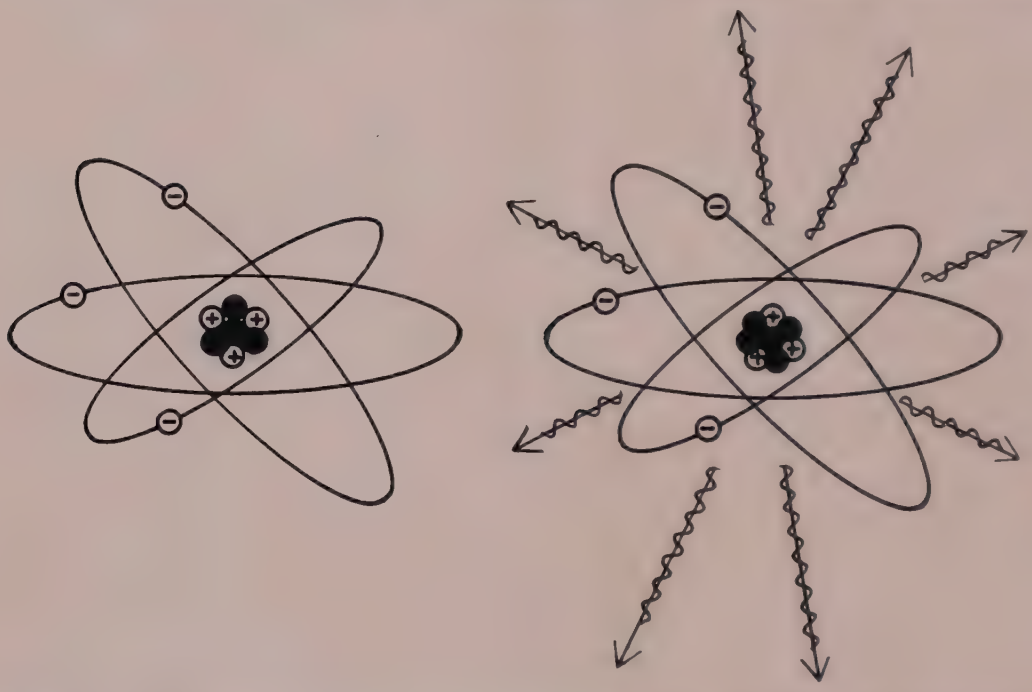


Figure 60. The same isotope: on the left the atom is stable—on the right the atom is radioactive and unstable.

of most elements by putting them in a nuclear reactor and bombarding them with neutrons. As a result of the bombardment the number of neutrons inside the nucleus is increased, usually by one neutron, and it is this that renders the nucleus unstable or radioactive. This instability causes radioisotopes to give off neutrons and gamma radiation and thus they can be detected.

It is because a radioisotope gives off this radiation, which can be easily detected with our instruments, that it can be of great use in medicine, agriculture, and industry. For instance,

radioisotopes can help to cure certain diseases, can assist in the control of insect pests, and can be used to process some types of hard polythene beakers so that they are resistant to rough treatment and certain corrosive chemicals.

These are the reasons why radioisotopes are so important today. By their use we can improve many of our industrial techniques, and thus save time and effort and make much better products.

The time taken for half the radioactive atoms of an isotope to break up or 'decay' is one of the features of a particular isotope, and this, its half-life, may be a fraction of a second or as much as several millions of years. The most useful radio-isotopes for industrial uses have half-lives of between a few hours and four or five years.

The radiation given off by a radioisotope can be detected by the use of a counter invented by Geiger, a German physicist and an assistant to Rutherford. This 'Geiger counter' consists of a small metal cylinder about the size of your thumb. In the centre of the cylinder is a thin metal rod. Radiation that goes inside the cylinder through the thin window causes a sudden discharge of electricity between the rod and the cylinder. These discharges can be counted automatically and registered on a

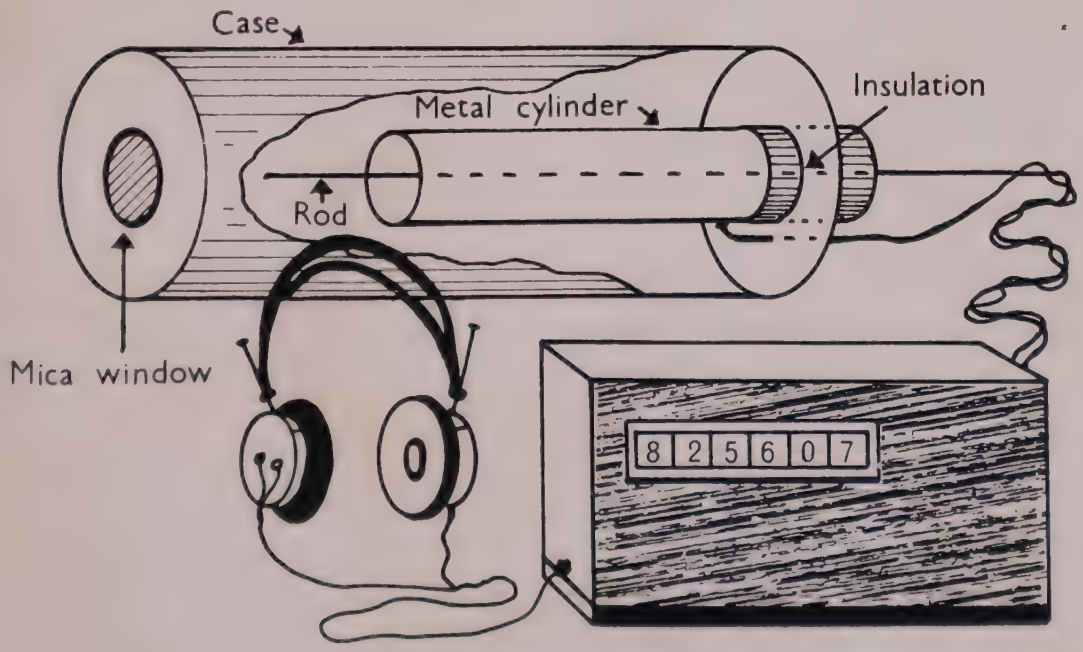


Figure 61. A Geiger counter with attached earphones.

Figure 62. A prospector searching for radioactive substances.

dial, or heard as clicks in earphones. The greater the number of clicks per second the stronger is the source of radiation.

Portable Geiger counters are carried by prospectors when searching the surface of the earth for radium, uranium, and other radioactive substances. When the prospectors hear an increase in the frequency of the clicks they know that radioactive rocks are near.

Question E.1. What are the medical uses of radioisotopes?

Today there are three main fields in which radioisotopes are being used in medicine. They help to relieve suffering in the case of some diseases, to find out where there are any irregularities in the blood stream, and to investigate the working of some of the vital processes of the human body.

The radiations given out by some of the radioisotopes are

Figure 63. A doctor wearing a lead-impregnated apron to protect himself from radiation as he examines a patient. The operator shown in Figure 22 also wears a similar apron when using X-rays.

so powerful that they can destroy the cells of which the human body is made. Therefore great care must be taken when handling radioisotopes, and doctors who use them on their patients have to wear special protective clothing. Rapidly growing or unhealthy tissue can be destroyed or damaged by a short exposure to radiation if this is applied carefully in the correct position so as to avoid hurting the healthy tissue. For example, the radioisotope cobalt 60 is ideal for this purpose because it gives out high-energy gamma radiation, it can be machined into the correct shape for application at the right position, and it is relatively cheap.

There are many occasions when the doctor needs to know if and where there are any obstructions in the blood stream. By injecting a radioisotope of phosphorus into the blood stream, the movement of the blood can be traced through the body by following the radiations of the radioisotope as it is pumped along by the heart. Small clots of blood discovered in this way can be dispersed by giving the patient pills to dissolve them, whereas if the clots were to be left undisturbed they might increase in size and cause a complete stoppage of the circulation of the blood and hence the patient's death.

The speed with which an organ of the body can absorb or

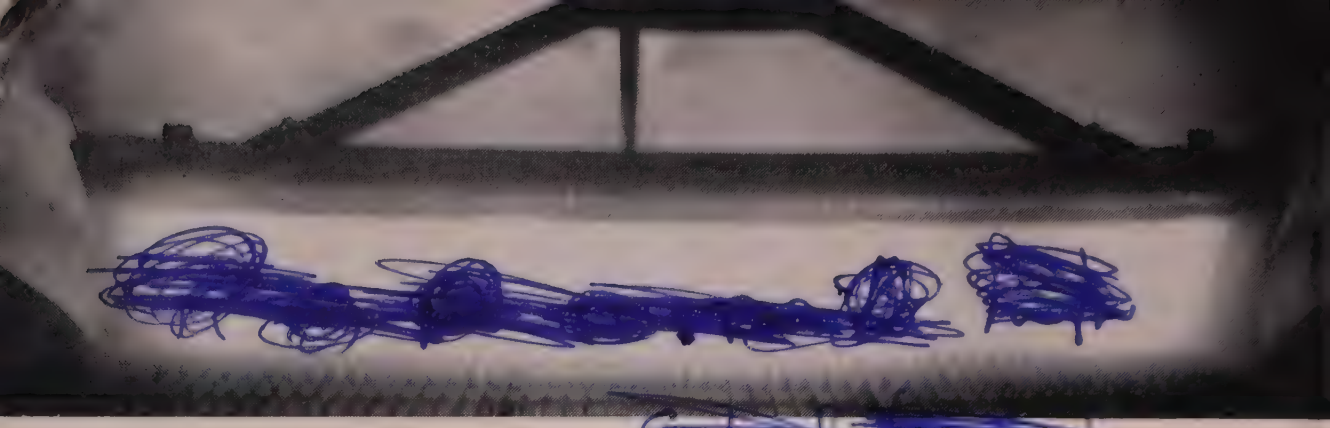


Figure 64. A photograph of the source of radiation used in the process of cold-sterilisation of heat-sensitive materials.

digest a particular substance can be found by including a radioisotope in the substance. Then by placing a Geiger counter in a suitable place it is possible to determine if the organ is healthy and working properly.

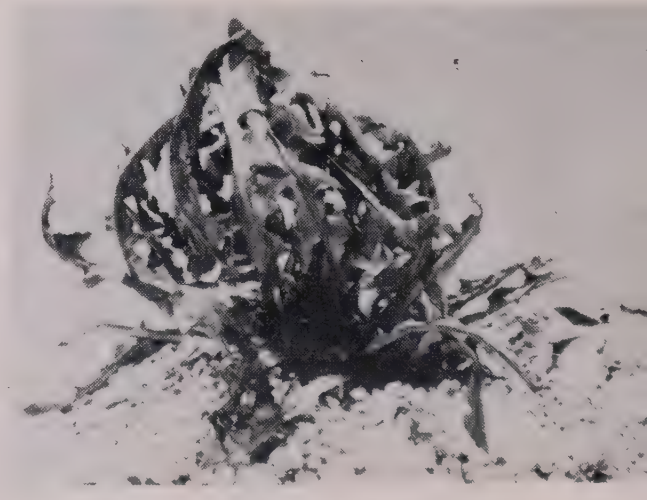
Doctors take advantage in a very large number of medical treatments of the techniques developed for the application and detection of radioisotopes, and their number is increasing every year.

Bacteria can be destroyed by large amounts of radiation such as are given off by some radioisotopes. As this is a cold process it is used to sterilise articles that would be damaged by steam or boiling water. Dressings, bandages, plastic containers, thermometers, hypodermic needles, and syringes are examples of heat-sensitive medical equipment which is sterilised in this way. This process is called irradiation. It has the added advantage that it is effective when the articles are already packed in sealed containers so that they will remain free from germs until they are used. The sterilised articles can thus be transported and used in far-away places where there are no local means of sterilising them.

Question E.2. What are the agricultural uses of radioisotopes?

Corn that becomes infested by insects is unfit for human consumption. By the use of radiations from radioisotopes some farmers kill these insects before they can do any damage, and hence prevent great losses of their stores of corn.

Seed potatoes stored during the winter months sometimes



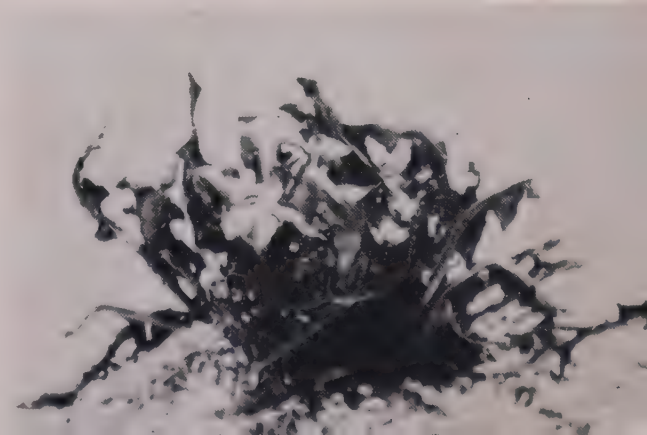


Figure 65. The photographs show the effect of a selective weed-killer on the growth of a dandelion. Above is the normally healthy plant before spraying; at first the plant grows on vigorously; it then outgrows its strength and the leaves curve in; and below within two or three days the plant collapses and withers away.

sprout too early and then rot, but if they are subjected to gentle radiations they will only sprout slowly and therefore will be preserved for planting in the spring.

Great improvement in the efficiency of pest-killers has been brought about by studying the movements of insect pests which have been labelled or sprayed with radioisotopes. Knowledge of the life history of these pests, their movements, and how they feed and breed, has helped research workers to find out the best way of killing them.

There are also many types of selective weed-killers that have been developed by observing the behaviour of weeds when treated with a chemical labelled with a radioactive isotope.

Better yields of milk from cows, and more eggs from hens, have resulted from the careful study of information gained by mixing radioisotopes with their normal feeding stuffs.

In order to test the efficiency of a fertiliser, research workers make

samples of it radioactive before spreading it over the soil. Once the plants have grown on the treated land, the workers are able by using Geiger counters not only to know exactly which parts of the plants have absorbed some of the fertiliser, but also how much they have taken in.

Seeds are known to produce some very peculiar strains of plants if they have been exposed to feeble doses of radioactivity. Some of them germinate and grow into giants, others become dwarfs, some produce fruit in abundance, whilst others are completely sterile. A new variety of peanut has been developed in this way which has a thicker shell, is more resistant to disease, and is also more prolific. New and exciting colours have been given to some of the flowering plants—who would have thought a few years ago that we could now grow red, white, and blue daffodils? Certainly Wordsworth did not dream of such a possibility!

All these and many more striking variations of plants and animals are being and will be produced by radioactivity. Some of these are superior to their parents in that they are better adapted to their environment or are more desirable for domestic or commercial purposes. They can be so selected for any particular purpose that when they breed they may produce even more desirable variations. This procedure forms the very basis upon which evolution is proceeding.

Question E.3. What are the industrial uses of radioisotopes?

Every branch of industry today benefits from the discovery of radioactivity and the properties of radioisotopes. There are hundreds of products that are made better, packed better, and wear better as a result of the research work of scientists using the methods of detecting radioisotopes. It is fortunate that so many elements can be made radioactive so that this kind of investigation can be undertaken. Industry has been enabled thereby to make great economies in the costs of manufacture as well as to make it easier and safer for those who work the machines.

Here, in this question we have only space to mention and describe a few of the many industrial uses of radioisotopes.

Figure 66. A French railway engineer using a Geiger counter to measure the wear on the wheels of this train.

The speed at which a large wheel is turning can be measured by placing a spot of radioactive paint on its rim and then using a Geiger counter to record the number of times this spot passes a certain position in a certain time.

A worker who has to put his arms near moving machinery can fasten on to his wrists bracelets which have been painted

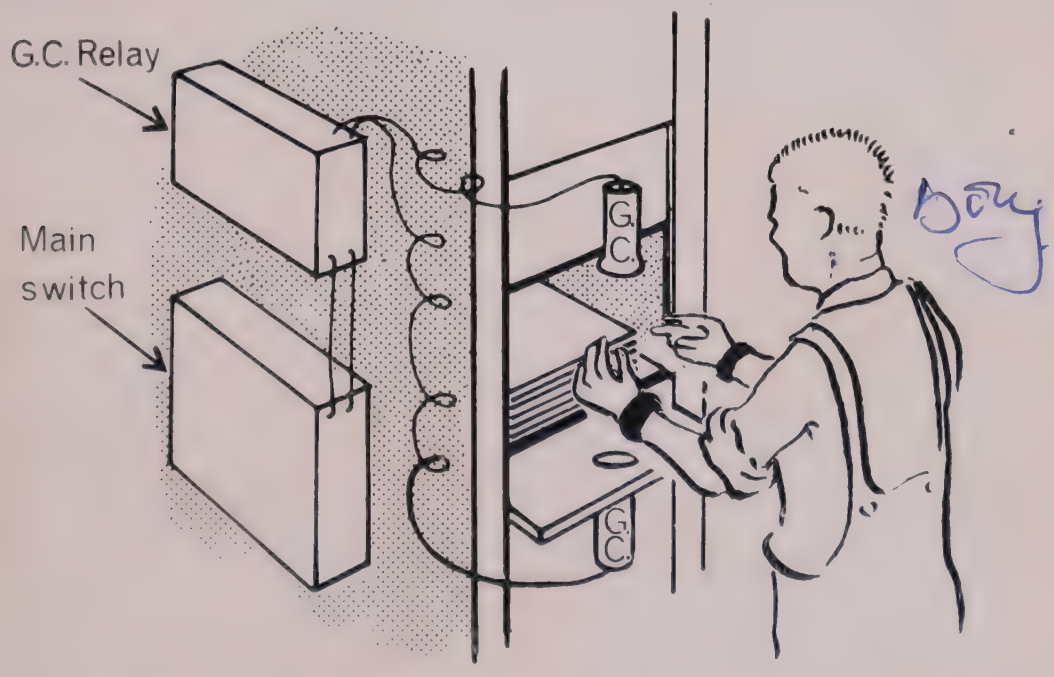


Figure 67. How two Geiger counters can be mounted so that they will prevent the knife of this cutting machine from moving whilst the operator's hands are in danger.

with radioactive material on the sides away from his wrists. Radiations collected by Geiger counters from these bracelets keep a relay open and prevent the machine from being turned on whilst his hands are in a position of danger.

Large quantities of crude oil from oil wells often have to be pumped considerable distances along pipelines. Sometimes it is necessary to change the quality or type of oil flowing through the pipe. Into the flow of oil at the exact position where the change takes place the engineers insert a small quantity of a radioactive substance. At the other end a Geiger counter is placed close to the pipeline to give a signal when the radioactive substance passes. This signal tells the engineers at that end when the change of oil has arrived.

Radioactive substances can also be used to detect a leakage in a pipe laid underground. To the liquid passing along the pipe a radioactive material or sometimes a quantity of the liquid itself made radioactive or even a radioisotope is added. Engineers, carrying Geiger counters and earphones, then walk along the ground over the pipeline and listen for any sign of increased radioactivity. When they hear that the clicks become more frequent they know that they are standing over the place where a leakage of the liquid is taking place. They can then

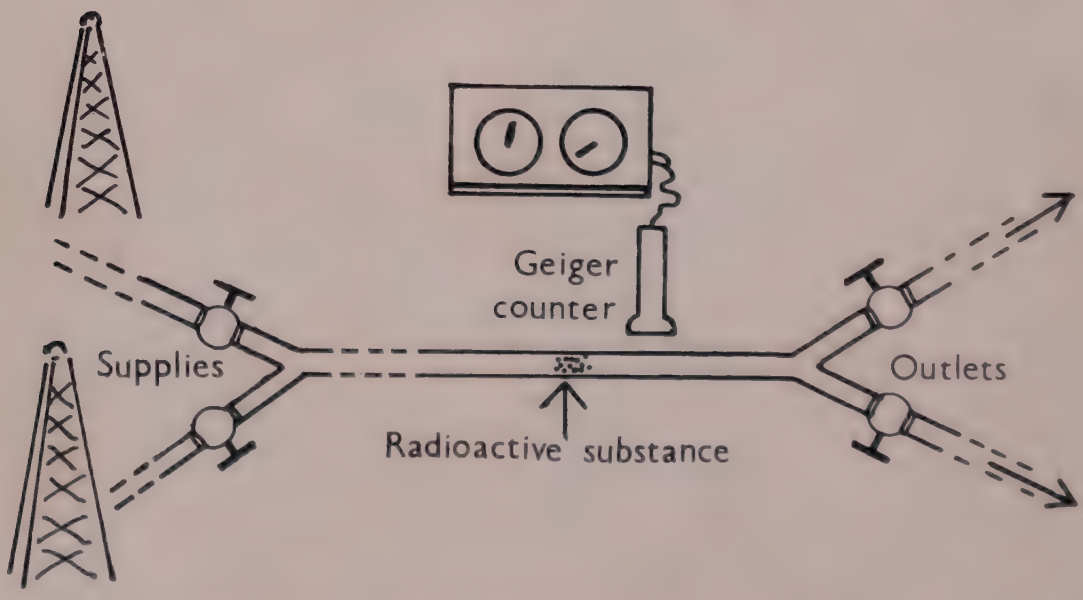


Figure 68. How one oil pipeline can be used to carry different grades of oil at different times.

Figure 69. A maintenance inspector using a Geiger counter to locate a leak in a pipeline.

direct those whose business it is to repair the pipe to the exact position where the crack is to be found.

Motor-car engine wear can be tested and the effect of various lubricating oils studied under normal road conditions and without having to dismantle the engine, by using radioactive piston rings. Engine wear, represented by the number of small particles of radioactive piston ring rubbed off by the cylinder walls, is estimated by a Geiger counter which is

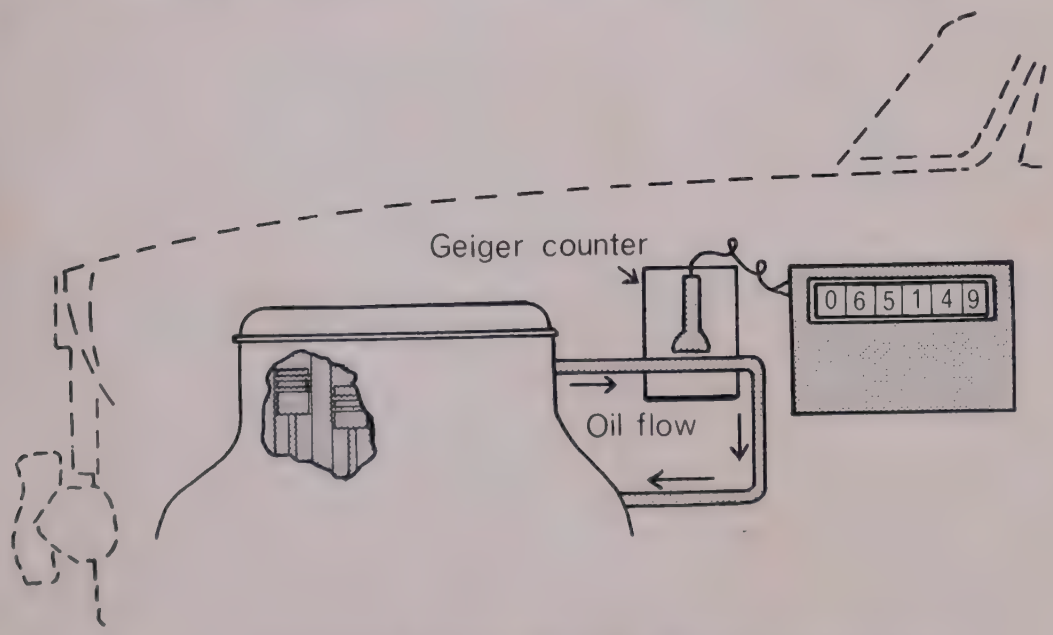


Figure 70. Measuring engine wear and testing lubricating oils.

placed inside the oil flow of the engine. The greater the count of radiation the greater the wear in the cylinders. The wear at high speeds is very much greater than at low speeds. Anyone who drives a car continuously at very high speeds, besides being a danger on the roads, shortens the life of his engine considerably.

It is always difficult to measure the quantity of liquid in a container which cannot be opened or weighed, especially if it has to be done quickly as on a moving conveyor belt in a factory. This can now be done by shooting gamma radiation at the container and measuring, by a Geiger counter placed on the opposite side, the absorption of the radiation. The same principle can be applied to measuring the thickness of any material. When plastic or steel is being rolled, the thickness of the sheet as it passes away from the rollers can be determined by measuring how much gamma radiation is absorbed. This enables the engineers to adjust the rollers immediately to correct any errors in the thickness of the output.

Carbon is found not only in the coal deposits of the forests

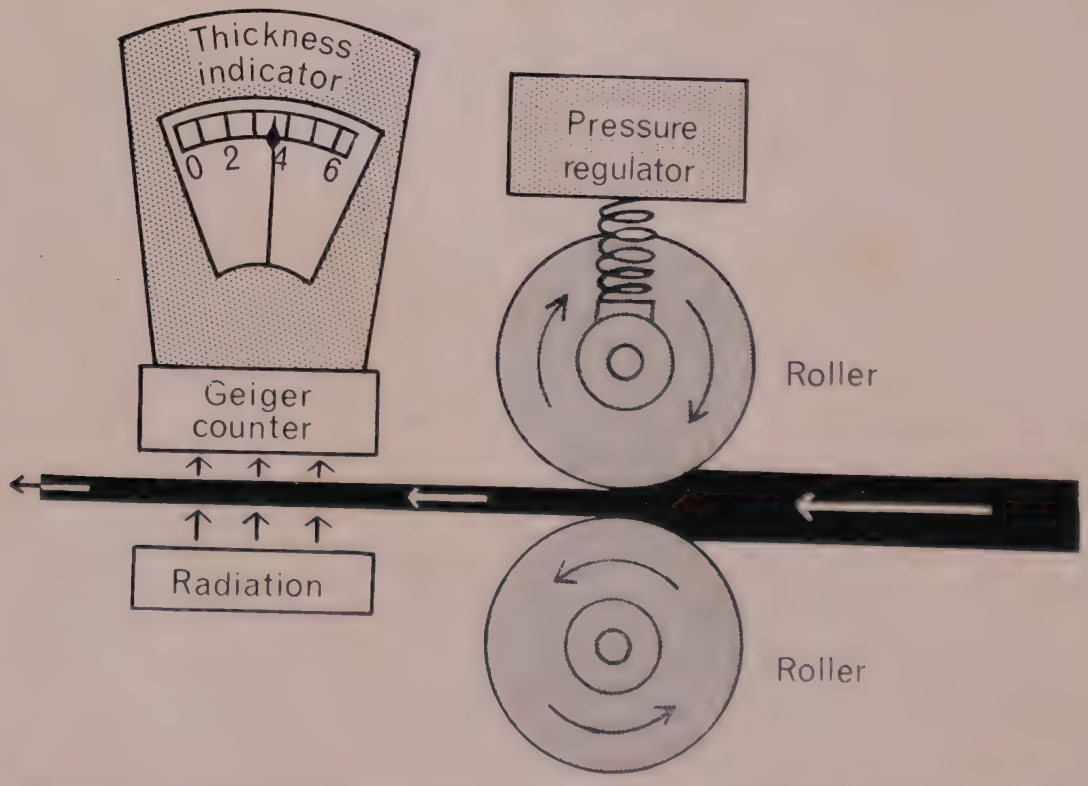
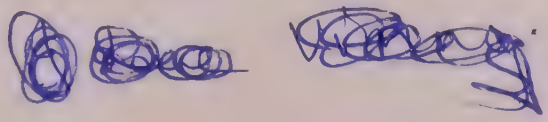


Figure 71. How a Geiger counter can be used to measure the thickness of material coming off a rolling mill.

of long ago but also in many other remains of plants, human beings, and animals. The carbon dioxide gas present in the atmosphere is absorbed by plants as part of their food. Animals eat plants and so they also contain many carbon compounds. One of the isotopes of carbon is radioactive. It is carbon 14 and has a half-life of about 5,500 years. By calculating what fraction of the radioisotope carbon 14 has disintegrated, our archaeologists and geologists can estimate the age of the carbon deposits in the remains found in the rocks that they investigate. Radio-carbon dating, as this is called, requires that a small quantity be taken away for investigation, of course, and unfortunately this sometimes spoils a precious rare specimen. Only about 6 per cent of the radioisotope carbon 14 is left after 44,000 years and this is too small to measure with any degree of certainty. Therefore the radio-carbon method of estimating ages older than this cannot be relied upon.

The radioisotope methods used in research and investigation are of very recent development. In the short survey in this book we have only had space to mention a few of the many hundreds of applications but sufficient to show what a great effect they are already having on our standards of living. They have helped us to solve many of the difficult problems we have faced in medicine, agriculture, and industry.



Some things to do

1 Make lists of all the uses of radioisotopes that you can read about in the books and see in the filmstrips and films mentioned below. List them in groups under the headings medical, agricultural, industrial, and others.

2 Ask your teacher if he can obtain for you some general information on the uses of radioisotopes from the Information Bureau, United Kingdom Atomic Energy Authority, 11 Charles II Street, London S.W.1. New uses are being found all the time so it is worth while asking for this information every year.

3 Take with you into a dark room a magnifying glass and a watch with a luminous dial. Rest your eyes for about 15

minutes in the dark and then examine the luminous parts of the dial. The flashes are due to the alpha particles, given off from the radioactive paint, striking a special mixture.

Wallcharts

From E.F.V.A.: *Atomic Theory*, Part 8, *Britain's Atomic Achievement*, and *Atomic Energy*, Part 2.

From Educational Productions Ltd: *Radioactivity*, No. C644/2.

Filmstrips

From E.F.V.A.: *Radioisotopes and their Uses*, No. 557 H 27.

Films

From E.F.V.A.: *The Discovery of Radioactivity*, No. 555 D 2.
From Rank Film Library: *Science for the Space Age: Atomic Energy—Inside the Atom.*

Books

J. MANDER. *Atoms at Work.* Newnes

J. M. A. LENIHAM. *Atomic Energy and its Applications.* Pitman (Advanced)

C. H. DOBINSON. *The Uses and Effects of Nuclear Energy.* Harrap

Problem F

What are the uses of nuclear energy?

One thing we have stressed all through this book is that man has by careful and patient investigation attempted to arrive at the truth of the structure of matter. He has travelled a very long way along this path of enquiry, he has devised the most ingenious experiments to test some superbly intelligent guesses. Never has so much energy and time been devoted as in recent years to advance his knowledge of science. Yet man does not know all the answers and there are still some most puzzling problems.

In the many fields of knowledge discussed we have seen how the scientists have been able to enrich our supplies of energy and improve our standards of living. One never knows what further advantages the scientists will bring to us as they attempt to satisfy their unlimited curiosity.

The best way to use nuclear energy, as we have discussed earlier, is to convert it into electrical energy. Electrical energy can then be used to perform nearly every task that we wish. Electricity is the cleanest, easiest, and most controllable form of energy. We have also discussed how neutrons, formed during the production of nuclear energy, can be used to supply us with radioisotopes.

There are really two main reasons that make nuclear energy so important both now and in the future. One is that a large quantity of energy can be produced from a minute quantity of raw material, and the second is that it is possible to convert the energy of nuclear fission slowly into electricity. These properties of nuclear energy make it especially valuable as a primary source of energy in situations where other sources of energy are difficult to obtain.

One of the most extraordinary communities has been built beneath the Arctic icecap about 800 miles from the North Pole in Greenland. It is Camp Century where American scientists and technicians are studying weather conditions in one of the most severe climates on earth. Their 'village' is

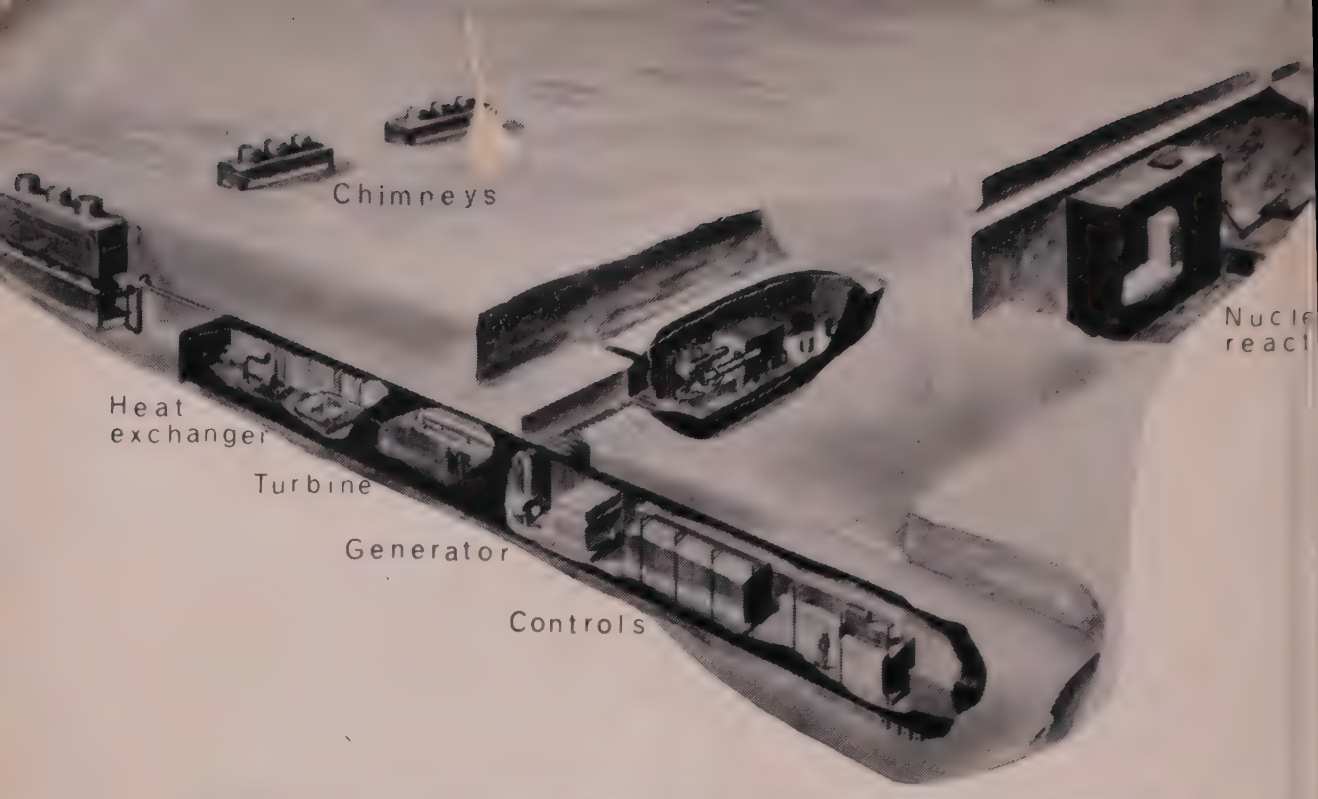


Figure 72. Nuclear energy generators provide comfortable living conditions in a weather station under the Arctic icecap.

lighted and heated by nuclear-powered electrical generators so that they live comfortably and work all the year round undisturbed by the bitter winter storms sweeping across the icecap above them.

Stations which convert matter into nuclear energy are being constructed in many countries. For some countries the need is more urgent than for others where large alternative sources of energy are available. It has been estimated that by about the year 1980 half of the world's energy supplies will be nuclear, and that by the year 2000, when children now at school will be grown-up citizens, it is likely that the whole supply of energy will be nuclear. Children of today may live in a world where there is no other commonly used source of energy.

Whilst it is true that at the time this account is written the slow release of nuclear energy from the fusion of light nuclei is not a practical proposition, many scientists think that this may be the final answer to the world's supply of energy, because nuclear fusion need not leave behind any radioactive waste products as nuclear fission does. It therefore has greater safety in operation. Another reason is that scientists think it may be possible to convert from nuclear energy of fusion directly to

electricity without the intermediate stages of coolant, heat exchanger, turbine, and electrical generator.

There are great hopes that nuclear energy will provide the world of man with unlimited resources and possibilities of better living.

Question F.1. How can nuclear energy be used for transport?

The nuclear energy stations constructed so far work because of nuclear fission and these have all needed heavy thick shields to absorb radiations which may be dangerous to the health of the operators tending them.

There is no difficulty in using nuclear energy for driving ships and submarines where the massive shields can be carried easily. It is convenient that the coolant and the moderator used in the nuclear reactors of submarines and ships is sea water. The design of these reactors allows for a large circulation of sea water. The energy derived from a piece of enriched uranium about the size of a marble is sufficient to drive a large merchant ship across the Atlantic ocean. Some such ships have already been built and these incorporate every possible precaution to prevent the spread of radioactive substances in the case of a collision.

Nuclear-powered submarines now cross the oceans—the first, the American *Nautilus*, launched in 1955 travelled 60,000 miles and used during the whole voyage 8 pounds of uranium. She also travelled in 1958 completely submerged for 100 hours under the North Polar icecap. This was not only a

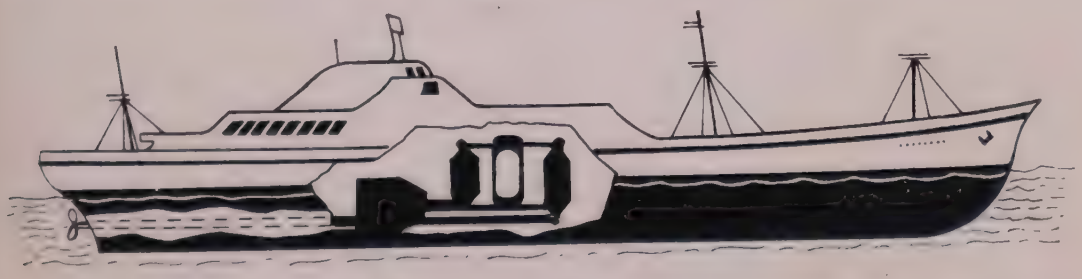


Figure 73. A drawing to show the position of the nuclear reactor, heat exchangers, and turbine in the American nuclear-powered merchant ship *Savannah*. It carries enough nuclear fuel in the reactor for more than three years' sailing.

Figure 74. The route of the first nuclear-powered submarine U.S.S. *Nautilus* under the Polar icecap in 1958.

great trial for a nuclear-powered underwater craft but also a spectacular feat of navigation by the crew.

The Russian icebreaker *Lenin*, launched in 1958, and the American merchant ship *Savannah*, launched in 1961, were the first nuclear-powered ships. Both can remain at sea for months at a time without returning for refuelling.

There is a great future for nuclear-powered big ships both on the surface and below where storms and winds have no effect on travel.

A nuclear-powered locomotive, automobile, or aircraft for the time being seems to be impossible to design. Nobody has yet been able to find a way of making the reactor itself and the shields cheap and light enough to be carried in small transport machines. Only big ships can carry the heavier load. Nevertheless there are many people working to find a way of making

light nuclear reactors and many more dreaming of the day when a nuclear-powered automobile will run for all its lifetime on a match-box full of nuclear fuel.

Perhaps nuclear energy will be the propellant for the future rockets that will carry men into space and back again. The day will surely come when man will travel far into outer space and return home safely to tell new stories of the great universe in which we on this planet are just one small item.

Question F.2. How can the human race share the blessings of nuclear energy?

Energy is a basic factor in our lives, whether it is used to grow our food, to produce our clothes, to warm our houses, to cure our ills, or to carry us around the world to meet our neighbours. We all strive to obtain as much energy as we can and to convert it into a form that is useful to us. The prosperity of any nation in the modern world can be judged by the consumption of energy per head of population. Our scientists are playing a great part in the struggle to obtain cheap and unlimited supplies of useful energy. Our designers and technicians are helping to turn the discoveries of the scientists into practical ways of producing this energy.

In spite of the different sources of energy available to man, many countries are relying on nuclear energy as the sole source capable of meeting their energy requirements in the future. They estimate that in about two decades nuclear energy will become the cheapest source of energy. The developing nations of the world will need energy on a large scale. They will be able to advance rapidly using the knowledge of the advanced countries to help them to construct nuclear energy stations from the start, instead of building the older solid fuel, oil, water, and wind-driven generating stations.

Scientists have achieved success by working patiently and thoroughly, by observing accurately, by thinking out new ideas, by trying out carefully designed experiments, and by being willing to abandon their ideas when better ones have been found in the process of building up new knowledge. Sometimes the scientists made intelligent guesses and then

performed experiments to test them, and sometimes carelessness or even a simple accident has enabled a clever and keen observer to lead the break-through to the next step forward.

The story of the search for energy from the nucleus of the atom is now told. It is not complete; but, as far as it goes, it is clear that scientists by their discoveries have placed into the hands of all men the possibility of generating energy in quantities undreamed of a century ago. Whether man will use the blessings that the discoveries can bring for the improvement of his standard of living, for the feeding of starving people, and for the relief of suffering is not only the concern of the scientist but also of all responsible men and women.

The responsibility placed on the shoulders of the leaders of the nations today is greater than at any time in world history: they can so easily destroy all that has been accomplished by using nuclear energy for the waging of a war which can only mean the end of civilisation as we know it today. The stakes are so great that all men must be brought to realise that only by international understanding and co-operation can we direct nuclear energy from the terrible possibility of world-wide destruction to the alternative peaceful uses for the enrichment of mankind.

Science is on the march in many ways—communications have so advanced that we can see and speak clearly and immediately to one another in any part of the world; transportation has so improved that within one day any one of us can shake hands with any other person on earth. In this kind of world we are all neighbours, and we must learn to live on friendly terms with one another. We can no longer consider ourselves as living in small national groups—we are international in every sense. Thus we must all act as citizens of one world and devote our endeavours to finding ways of spreading the blessings of nuclear energy for construction rather than destruction.

To change the outlook of men towards co-operation in the world will take time. Men's thoughts change slowly. It will mean greater mixing of peoples not only for pleasure but for the affairs of everyday life. It will mean learning to accept and

appreciate the interests and cultures of other people. This will require a determined effort and good education.

Nuclear energy if used constructively will enable the people of the world to do the work they have to do in order to provide the food and the commodities they need in greater ease and in less working time. This creates a problem because all of us will have much more leisure time. So many of us now feel that it is urgent to prepare ourselves for the wise use of this greater leisure time which is approaching rapidly. We can do this partly at school by taking every opportunity that exists there to acquire wide interests in as many forms of activities as possible, in hobbies, skills, recreations, and in reading. These opportunities are with us now if we will take advantage of them.

It is good that we have learned in this book something of the rich possibilities of this rapidly approaching age of nuclear energy.

Some things to do

At the end of this study there is another wallchart which is worthy of display, and no doubt if you search you will find others.

Wallchart

From E.F.V.A.: *Britain's Atoms Serve Mankind.*

Filmstrips

From E.F.V.A.: *Structure of Matter. Part 2, Atomic Energy*, No. 558 G5.

From Common Ground: *Nuclear Energy*, No. CGB 693.

Films

From E.F.V.A.: *Conquest of the Atom*, No. 557 D 17. This gives a good summary of the subject of the book.

From the Foundation Film Library, Brooklands House, Weybridge, Surrey: *A New Reality.* A film which surveys elementary nuclear physics at a popular level.

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Books

W. R. ANDERSON. *Nautilus 90 North.* Hodder & Stoughton

SIR CHRISTOPHER HINTON. B.B.C. *The A.B.C. of Atomic Energy.*

The World within the Atom. Westinghouse Electric Corporation, Pittsburgh, U.S.A. (Free issue)

F. R. ELWELL. *Atoms and Energy.* Methuen

L. A. REDMAN. *Nuclear Energy.* Oxford University Press

E. C. ROBERSON. *True Book about Atomic Energy.* Muller

E. W. TITTERTON. *Facing the Atomic Future.* Macmillan (Advanced)

Nuclear Energy in Britain. Central Office of Information, H.M.S.O.

Much interesting information is to be found in *Science Club* published six times a year for secondary school pupils by Junior Club Publications Ltd, 60 Paddington Street, London W.1.

ANSWERS TO QUESTIONS ON PAGES 46 AND 47

1, *c.*	2, *a.*	3, *b.*	4, *c.*
5, *c.*	6, *c.*	7, *d.*	8, *e.*
9, *f.*	10, *b.*	11, *c.*	12, *c.*
13, *f.*	14, *c.*	15, *c.*	16, *b.*

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